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ABSTRACT

Objectives: To assess the clinical evidence regarding the performance and safety of VPT as compared to RCT. As well as to compare the different techniques and materials associated to VPT and their outcomes.

Materials and Methods: A bibliographic review is performed by investigating several databases: PubMed, MEDLINE, Biblioteca CRAI Dulce Chacón, ResearchGate and Google. Articles have been selected according to defined inclusion criteria such as a ten-years range with relevant key words. 25 studies were included, most of them being controlled randomized clinical trials.

Discussion of the Results: 6 comparative studies were used to measure the performance of VPT and RCT according to three parameters being post-operative pain, clinical success rate and economic evaluation. Studies reported that VPT had relatively more encouraging results than RCT.

21 studies were selected to compare both the techniques and materials of VPT and their outcomes. They showed that as to the techniques, the partial removal curettage had better issues than any other. As for materials, Biodentine, MTA and GIC seemed to have similar results according to their clinical evidence for VPT, making CaOH an unsuitable choice.

Conclusions: Although results presented more favourable outcomes for VPT, there was insufficient evidence to identify and conclude which treatment is best in terms of safeness, success, and economical aspect. However, maintaining and preserving pulp vitality is the main objective of today's practice that prones to be more conservative, through pulp capping techniques that offer the safest and therefore the best option.

RESUMEN

Objetivos: Evaluar la evidencia clínica con respecto al rendimiento y la seguridad de la TPV en comparación con los TCR. Así como comparar las diferentes técnicas y materiales asociados a TPV y sus resultados.

Materiales y Métodos: Se realiza una revisión bibliográfica investigando varias bases de datos: PubMed, MEDLINE, Biblioteca CRAI Dulce Chacón, ResearchGate y Google. Los artículos se han seleccionado de acuerdo con criterios de inclusión definidos, como un rango de diez años con palabras clave relevantes. Se incluyeron 25 estudios, la mayoría de ellos siendo ensayos clínicos controlados aleatorios.

Discusión de los Resultados: Se utilizaron 6 estudios comparativos para medir el rendimiento de TPV y TCR según tres parámetros: dolor posoperatorio, tasa de éxito clínico y evaluación económica. Los estudios informaron que la TPV tuvo resultados relativamente más alentadores que los TCR. Se seleccionaron 21 estudios para comparar tanto las técnicas como los materiales de TPV y sus resultados. Demostraron que, en cuanto a las técnicas, el legrado de extracción parcial tenía mejores problemas que cualquier otro. En cuanto a los materiales, Biodentina, MTA y CVI parecían tener resultados similares según su evidencia clínica de TPV, lo que hace que el CaOH sea una opción inadecuada.

Conclusiones: Aunque los resultados presentaron resultados más favorables para la TPV, no hubo evidencia suficiente para identificar y concluir cuál es el tratamiento de elección de acuerdo con la seguridad, el éxito y el aspecto económico. Sin embargo, mantener y preservar la vitalidad pulpar es el principal objetivo de la práctica actual que tiende a ser más conservadora, mediante

técnicas de recubrimiento pulpar que ofrecen la opción más segura y, por tanto, la mejor.

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1. INTRODUCTION

1.1. Pulp affectation in carious process

The carious process causes an abundant secretion of acids and toxins by cariogenic bacteria. Acidity causes a more or less rapid demineralization of mineralized dental tissue. Then, a cavitation spreading within the different layers of the tooth appears. Enamel is the first to be impacted, dentin is only second. And if no treatment is performed, the dental pulp is damaged (1).

Dental pulp is the central element of the tooth, allowing it, thanks to its vasculo-nervous network, to answer and to adapt to various stimuli. This organ, made of connective tissue, is responsible for cellular differentiation, neuro-sensorial functions, vascularization as well as adaptation possibilities and tooth repair (2,3). An inflammatory reaction of the dental pulp may appear in the event of a carious lesion. This inflammation can be acute or chronic and compromises the vitality of the tooth. Pulp exposure to the oral environment can be caused by a traumatic, carious or previous restorative event that have led to a rupture of the mineralized layers (dentin and enamel) (4).

1.2. What is Vital Pulp Therapy?

For a long time, an affected pulp has been considered as devoid of healing power. This is why the classical major therapy recommended for permanent mature teeth suffering a pulp exposure is the Root Canal Treatment (RCT), consisting in the excision of the entire dental pulp and the plugging of the pulp space with an inert, synthetic material (2). This treatment aims to avoid any

infectious and/or painful complications. The latter has been known for many years as predictable and reliable.

Vital Pulp Therapy (VPT) is a restorative dental treatment which goal is to conserve and sustain compromised pulp tissue of teeth that have suffered a particular event, by relying on the scar capacity of this living tissue. It is defined as a treatment which intention is to trigger the development of reparative dentin to uphold the tooth as a functional unit. It is the capability of healthy pulp to repair traumatized pulp in the absence of bacterial contamination (4).

The outcomes of VPT will depend on a few variables, for instance: the age of the patient, the size of the pulp chamber, the pulp capping materials chosen, the microbial contamination and the quality of the final restoration (5).

It is important to understand the difference between a repair and a regeneration. Indeed, VPT is a repairing treatment that occurs when the damaged tissue is still vital, therefore inducing a healing; while a regeneration is a treatment only done when the pulp is completely necrotic. In the repair, the healing takes place by proliferation of connective tissue elements, not resulting in an exact replica of normal pulp tissue but more of a bonelike or periodontal-like tissue; while in the regeneration, this same process happens by proliferation of parenchymal cells, resulting in a complete restoration of the original tissue, closely resembling to a normal pulp tissue (6).

1.3. Goal of VPT

In permanent mature teeth with a closed apex, the primary goal of the VPT is the establishment of a dentinal bridge with the following course of action: first by stimulating either undifferentiated mesenchymal cells or pre-existing

odontoblasts, the mesenchymal cells will become odontoblasts that will produce reparative dentin, whereas already-existing odontoblast will produce reactionary dentin, both dentins will create the tertiary dentin wanted for the formation of the dentin bridge (4).

1.4. Evolution

It has been indicated that VPT should be performed only in deciduous teeth, who have a temporary stay on the dental arch, due to the high healing capacity of pulp tissue compared to permanent ones. This therapeutic method has also been implemented to treat trauma inducing a slight pulp exposure on immature permanent teeth in order to maintain the radicular growth process and the closure of the apex (4).

The indication for VPT is broadening significantly towards permanent teeth, since the evidence that the patient's age and therefore the status of the apex failed to indicate that VPT could not be performed successfully in old patients, as shown by many new studies published each year on this subject.

It has been proven to be a reliable alternative to RCT, based on the innate capacity of pulp tissue for repair in the absence of microbial contamination (7). The therapeutic perspectives of VPT are interesting and follow the current logic of tissue preservation.

1.5. Indications

VPT is a technique allowing the preservation of pulp vitality. However, it is not the only one to allow this. There are other treatments which mostly use similar materials; only their clinical implementation differs. The choice will relate to one of the techniques depending on the patient's age, the pathology present, the

periapical state, the tooth liabilities, its functional role and also the general history. A factor having a value of crucial significance in VPT is the state of the pulp tissue, as well as the degree of pulpal bleeding; both being good indicators of the pulpal inflammatory state (4).

It is widely thought that VPT was designed and planned to only be carried out in teeth with symptomatology and signs of a reversible pulp inflammation. The arising question is the following: how can we accurately establish the status of the pulp (4)? Research suggests that the clinical pulp diagnosis should be reviewed, better classifying symptoms and clinical signs such as sensibility and pain testing, in order to avoid any misleading conclusion in terms of prognosis and treatment and to give us a better accuracy in the reflection of pulp condition (8).

Numerous studies have described prosperous treatment results in vital teeth presenting an exposed pulp with symptomatology and signs of what would appear to be diagnosed as irreversible pulpitis and periapical lesions (9).

The improvement in knowledge and understanding of caries and tooth defence phenomena, in parallel with the ever-increasing development of our treatments, has resulted in an increase in the number of indications for certain treatments.

1.6. Techniques for VPT

VPT includes indirect and direct pulp capping, depending on whether there is a pulp exposure or not (4). VPT also counts the pulpotomy, widely used for exposed pulp in deciduous teeth or permanent immature teeth, that can also be

used for permanent mature teeth in the case where pulp was exposed traumatically. The common objective is to induce a physical protective barrier over the pulp in order to maintain its function and vitality.

1.6.1. Indirect Pulp Capping (IPC)

IPC is a technique which involves placing a biocompatible protective element next to the pulp after complete caries removal. It is indicated when there is a thin portion – less than 0.5mm – of carious juxtapulpal dentin left that if removed, would expose the pulp. In fact, the presence of contaminated underlying dentinal tubules and their communications with the pulp can cause a pulpal contamination comparable to true pulpal exposure (10).

There are two types of IPC: the one by stepwise excavation of caries, consisting in removing the carious dentin during appointments over a period of months or a year, each time recovered by a glass ionomer or calcium hydroxide base in order to stimulate between each removal the remineralization of underlying tissue. Thus, leaving the deeper affected dentin more suited to create a tertiary dentin. And the other type of IPC is the one without re-entry and further excavation, having the same goal as the latter but with the innermost layer of carious dentin voluntarily and permanently left (11,12).

1.6.2. Direct Pulp Capping (DPC)

Direct pulp capping is a method intended for deep caries disease that directly or indirectly results in the exposure of a small part of pulp tissue. A biocompatible material is placed over the area of interest and is subsequently covered with a permanent coronary filling. It is indicated for pulpal intrusion of

small size less than 1 millimetre. This damage can be caused by a traumatic event, by dental caries or during the eviction of the latter by the operator (13,14).

1.6.3. Pulpotomy

This approach involves the clearance of the degenerative and irritated part of the pulp, but without the full removal all pulp tissue, thus leaving healthy pulp intact. A glass ionomer layer is placed over the remaining pulp, in order to keep intact its vitality and functions (12,15). This technique is indicated in permanent teeth when there will be signs of irreversible pulpitis with vital pulp still remaining.

1.7. Materials used for VPT

New materials such as the Calcium Hydroxide, the MTA, the Biodentine™ and CEM have been discovered and evaluated specifically for this therapy.

1.7.1. Calcium hydroxide (CaOH)

Calcium hydroxide has been the most widely used material in conservative dentistry because of its reasonable cost, ease of use, clinical history and multiple chemical and biological advantages (10). However, it causes more superficial necrosis than preparations available on the market. The latter are easier to use, they harden via the action of a catalyst. Calcium hydroxide does not have good mechanical qualities: it has low compressive strength, low sealing, low reaction capacity against acid etching. Its degradation over time occurs very quickly. It is therefore compulsory to cover it after using a material with sufficient mechanical properties. Currently, the emergence of new biomaterials no longer makes calcium hydroxide a material of choice for VPT techniques (16).

1.7.2. Mineral Trioxide Aggregate (MTA)

The MTA is very frequently used in the context of direct pulp capping and pulpotomy (17). However, it has some drawbacks that can sometimes direct the operator to another material. Indeed, MTA presents some disadvantages not insignificant: its setting time is relatively long (three to four hours), it is a very expensive preparation, it is difficult to work with, since it must be prepared manually, so it is a dependent operator, it stains and is associated with dyschromia on treated teeth that causes strong aesthetic damage, especially for the anterior teeth. MTA is therefore not a consensual product for different pulp capping (18).

1.7.3. Biodentine™

Biodentine™ is an antibacterial, anti-inflammatory, haemostatic, radiopaque material and causes the appearance of an area of necrosis. It has a setting time of approximately 20 minutes. This cement has properties intended to be similar to dentin. Compared to the materials mentioned above, Biodentine™ is dimensionally stable. In addition, its compressive strength increases after its setting reaction (16,19). The adhesion of this material and its tightness are excellent. It is a biocompatible cement and like calcium hydroxide, it has a bioactivity responsible for the reformation of dentinal bridges and causes an osteoinductive action, favourable to the preservation of the tooth. The use of this product is increasingly common. It is an expensive material. Biodentine™ is currently well studied, its success rate is excellent. However, its recent arrival on the market does not yet allow sufficient clinical experience to make it a consensual product today (19).

1.7.4. Calcium Enriched Mixture Cement (CEM)

CEM or NEC (Novel Endodontic Cement) is a new product. It was developed in order to benefit from the many advantages of the MTA while excluding its disadvantages. Thus, CEM is a biocompatible, bioactive and waterproof material with low cost, ease of handling and shortened setting time (20).

The evolution of materials and techniques allows a more conservative approach to our therapies as well as a tightness of the dentin-pulp complex suitable for maintaining pulp vitality (21).

2. OBJECTIVES

MAIN OBJECTIVE

To assess the clinical evidence regarding the performance and safety of VPT as compared to RCT.

SECONDARY OBJECTIVES

1. To compare the different techniques associated to VPT and their outcomes.
2. To compare the different materials used for VPT and their outcomes.

3. METHODOLOGY

To find the articles, I used the *PubMed*, *MEDLINE* and *ResearchGate* databases as well as the website of the UEM CRAI Dulce Chacón library. I typed the following keywords: “vital pulp therapy” “pulp regeneration” “permanent teeth” “mature permanent teeth” “pulp capping” “techniques for vital pulp therapy” “materials for vital pulp therapy” “treatment for irreversible pulpitis” “reversible pulpitis” “comparative studies between capping materials”.

94 articles were first selected without looking at the selection criteria, and it ended up with 57 by selecting exclusively the ones within the last decade. One important inclusion criteria was the language, excluding all articles not written in English. As well as studies carried out on patients with mature permanent teeth.

I prioritized the articles coming from the following journals: *Journal of Endodontics*, *International Endodontic Journal*, *Australian Endodontic Journal*, *Journal of dentistry*, *Iranian Endodontic Journal*, *European and Endodontic Journal*. But some articles that I found very relevant also come from other books.

I also looked at the references that were used by certain authors to write their articles and used some of them.

4. DISCUSSION OF RESULTS

4.1. VPT VS. RCT

The RCT induces a weakening of the tooth, depriving it of its defence capacities, which rises quite a challenge concerning the medium to long-term prognosis for those teeth. Currently, maintaining the pulpal vitality is the major goal of conservative therapeutics. This is why it is legitimate to wonder about the effectiveness and benefits of treatment by VPT of mature symptomatic permanent teeth so as to implement a minimally invasive treatment (22).

VPT is of great profit to dentists as a substitute to RCT, as it could be advantageous for patients with permanent dentition because it is going to support, maintain, restore or save survival of the tooth, especially molars (4). Since the forces applied on teeth at the time of mastication are very elevated, treated teeth with RCT are often more vulnerable, thus susceptible of structural collapse, deprivation of sensation or environmental alterations, engendering to more or aggravated caries, reinfection, and appearance of apical periodontitis (4).

Favourable outcome of VPT will depend on several determinants such as the extent of infected tissue, a healthy periodontium, an appropriate blood supply to the tooth, the ability to build a proper coronal closure.

Various studies (Schwendicke 2014, Cousson 2014, Asgary 2015, Galani 2017, Eren 2018, Seck 2018) have tried to compare VPT with RCT, considering post-operative pain intensity (23), clinical success rate (24–27) and costs (28).

4.1.1. Post-operative pain comparison

(Annex 1 – Table of studies comparing post-operative pain reduction in VPT & RCT).

Results have shown that short-term pain was more pronounced in teeth receiving RCT compared with partial pulpectomy or pulpotomies using ZOE. Although pain notably receded after days in all groups, it has been noticed that in pulpotomies using MTA, pain remarkably diminished earlier than in RCT.

4.1.2. Clinical success rate comparison

The study of Seck of 2018 has been used to prove a certain success rate as to VPT, only including patients with mature molars with irreversible pulpitis. Prior to interpretation of results, success rate was defined by an absence of inflammation, infection and tenderness to percussion, either being by radiological and/or clinical assessment. Both VPT by pulpotomy and RCT were compared in a randomized clinical trial. The outcomes of this study showed a favourable success rate for VPT, although the proportion of success was not significantly different – 21.9% of failure for VPT and 24.7% for RCT – in a five-year follow-up period (29).

4.1.3. Economic evaluation

The last criteria used to compare VPT and RCT was the economic evaluation by the cost-effectiveness analysis of both techniques. The study of Schwendicke was conducted in 2018 in Germany, thus based on the German health model. It resulted in concluding that VPT by DPC comes off as more cost-effective in comparison with RCT over a lifetime period. However, this analysis being conducted only with one patient, when running more sensitive analysis,

VPT was not found to be particularly more cost-effective than RCT, especially in patients over 40 years of age and in teeth with a proximal pulp exposure site (28).

Those results may have some limitations, size of the sample for example, is incorrect in the study of Seck. But also, a lack of support, in the Schwendicke analysis, that makes it difficult to apply it to other countries and other models and systems. Moreover, there is a huge variety of techniques used, when comparing DPC or pulpotomy with RCT and such differences in materials used, resulting in a lack of evidence, not letting us conclude that a technique is better than the other, therefore, an uncertainty in findings.

4.2. Clinical outcomes of different techniques

The treatment of carious lesions has traditionally implied the complete elimination of carious tissue before placing a restoration. Histologically and clinically, dentinal caries has been characterised as having two distinct layers (29):

- The outermost area where the dentin is strongly demineralized, the collagen is utterly contaminated with bacteria (often referred to as the infected area),
- The innermost area where the dentin is demineralized but the collagen is sound and a little infected (often referred to as the affected area)

Knowing how far decayed dentin must be withdrawn in order to stop the carious course of action is a problem that has existed for many years, whether it would be better to leave the affected dentin to protect the pulp or remove it and risk a pulp exposure (30).

In 2008, Lars Bjørndal conducted a survey on the attitude of dentists facing a deep carious lesion for which a risk of pulp penetration is to be

considered. Results showed that 62% of dentists would remove all decay, 18% would perform partial curettage, and 20% would undertake first-line endodontic treatment (1,12). However, the survival expectancy of devitalized teeth being of poorer quality to that of vital teeth, especially molars (31), the vital pulp should be conserved if possible in the following situations: in case of reversible pulpitis without periapical pathology, in mechanical pulp exposure or in recent traumatic pulp exposure (4).

Consequently, the dentist must be aware of the different possibilities that exist in order to avoid the endodontic treatment. 4 methods that allow the maintenance of pulp vitality will be listed, from the least invasive to the most invasive, in the following paragraphs.

4.2.1. The Indirect Pulp Treatment (IPT)

The IPT includes several procedures that aim to prevent pulp invasion during carious curettage of deep decay. “Stepwise” and “partial removal” techniques involve removing the non-remineralizable tissue and leaving a thin layer of caries tissue at the pulp wall, while the axial walls are carefully curetted (32).

The surface layer of decayed dentin (which contains the majority of microorganisms and their toxic products) must be removed to allow the pulp to heal. The affected dentin can be kept in the deeper parts of the cavity preparation because this area contains few microorganisms. The thickness of the residual dentin after caries excavation is a determining factor in the condition of the pulp and only the operator will be able to judge (13).

More recently, certain authors such as Schwendicke (13,33), Bjørndal (33) and Maltz (34) have taken an interest in the subject and have demonstrated a strong decrease in the number of pulp invasion compared to complete curettage.

4.2.1.1. The “stepwise” technique

This method is carried out in two stages and this is where the difference lies from the so-called "partial removal" technique.

In the first session all the carious tissue is removed from the axial walls of the cavity, in order to create a healthy dentin/enamel surface. This is essential in order to obtain good bonding and therefore a significant seal between the cavity and the restoration (35,36). Subsequently, all the infected dentin is removed using a bur mounted on a contra-angle at low speed under spray, or using a manual excavator, without exerting excessive pressure. Sufficient thickness of the affected dentin is preserved at the pulp wall to prevent any pulpal invasion. Once this curettage is performed, a dentin-pulpal protection based on calcium hydroxide or a zinc oxide-eugenol cement is placed on the pulp wall and a temporary waterproof restoration covers it (37).

At the second appointment, the provisional restoration and pulp protection are removed, then the carious tissue left in place at the first appointment is curetted. Once the cavity has been cleaned, a new pulp-dentin protection is installed, and a definitive restoration will be made (33,37).
A careful and meticulous monitoring of pulp vitality and the seal of the restoration will be performed at 6 weeks, 3 months, 6 months and then annually (38).

4.2.1.2. The “partial removal” technique

Otherwise called Atraumatic Restorative Treatment (ART). In this technique, the curettage of the axial and pulp walls will be carried out as

described previously in the stepwise technique. Since the definitive restoration will be performed in the same session, so there will be no reopening. The pulp-dentin protection material placed under the final restoration should therefore allow remineralization of the underlying dentin (38).

4.2.1.3. Results and outcomes

According to five clinical studies , IPT is recommended for the treatment of teeth with deep caries lesions and asymptomatic pulpal inflammation; provided that the restoration is perfectly sealed (regardless of the restoration material chosen) (13,33).

The clinical evaluation of the carious tissue during the decay removal step is important. Indeed, the condition of the dentin that is not removed can influence how well the therapy works. Under these conditions, residual bacteria are isolated from sources of their nutrients, stop growing and die. This results in a reduction in the number of microorganisms and the cessation of active lesions after IPT (34–36,39,40).

Studies have shown that teeth treated with IPT methods remain asymptomatic and free from radiological abnormalities for several years. The pulp maintains its healing potential and its defense capabilities against the advancement of caries lesions. It acts as the best barrier against bacterial invasion. There will be no harm to pulpal health and the caries process will stop (34–36,39,40).

(Annex 2 & 3 – Analysis of selected studies).

4.2.2. Indirect Pulp Capping (IPC)

IPC is a technique for placing a pulp protection material next to the pulp after complete or partial caries curettage (on affected dentin only), when the residual dentin thickness is low and irritation pulp is predictable (33).

However, after caries eviction, even complete, the presence of bacteria is still detectable. The pulp protection material must therefore ensure the destruction of the last cariogenic microorganisms present, must induce the remineralization of the collagenous fabric of the affected dentin and/or reduce pulpal inflammation.

There are two schools when it comes to customary catering (11–14):

- The cavity is temporarily sealed for 3 to 6 weeks then during a second appointment by placing a customary restoration.
- The cavity is sealed directly with a restoration used at the first appointment.

As previously said, the tooth must respond positively to pulp sensitivity tests and must present a symptomatology that can be classified in categories I or II of Baume (Annex 4). After complete caries curettage, when the juxta-pulp residual dentin thickness is less than 0.5 mm, the number and size of open dentinal tubules causes the pulpal parenchyma to communicate with the oral environment comparable to a true pulp exposure (13,14). Pulp protection is therefore necessary and essential to suppress inflammation of the pulp, bring a return to a physiological state of the pulp and finally allow lasting coronary restoration, if the residual dentin thickness is less than 0.5 mm. The material should ensure optimum sealing, allow sclerosis of the dentinal tubules, and induce the formation of reactive dentin. Finally, this pulp protection must have anti-bacterial and anti-inflammatory properties (11).

According to several studies (14), the IPC method represents a good alternative to RCT, if it is combined with partial curettage to decrease the risk of pulp exposure, and after placing MTA as pulpo-dentin protection when juxta-pulp residual dentin thickness is less than 0.5 mm. No pulp protection is mandatory for capping more than 0.5 mm from the pulp, before composite reconstitution with a self-etching system.

In 2013, Ricketts (11,41) has shown that when no pulp invasion is to be deplored, the success rate of IPC is 89.9%. However, the incidence of iatrogenic pulp invasion is significant: around 34.7%.

In 2014, another study from Asgary (41) showed a success rate of IPC of 100% after 1 year of follow-up.

4.2.3. Direct Pulp Capping (DPC)

Direct pulp capping may be used in the event of minimal pulp exposure, caused by trauma or by complete caries curettage of deep decay. Only teeth with Baume type I or II symptomatology (Annex 4) are concerned by this technique. Apart from sensitivity testing and pain, the extent of bleeding from exposed pulp tissue was used as a factor to assess the condition of pulpal tissue as part of the preoperative diagnosis (11) . The level of bleeding from the exposed pulp may reflect the inflammatory degree of the pulp. Massive tissue bleeding usually signifies a pulp with little or no chance of convalescence. Bleeding on exposure increases the risk of pulp inflammation and the presence of irreversible pulpitis (15).

The study of Dammaschke in 2010 concludes that in the case of teeth with spontaneous pain or discomfort prior to treatment, DPC should be avoided. The cavities should be restored with a bacteria-proof filling material immediately

after DPC. Inlays, crowns, or other costly restorations should not be considered until 2 years after pulp capping. In addition, the differences in the success rate of this treatment in the different studies lie in the cause of the pulpal exposure (42).

In his study of 2010, Bjørndal compared DPC with partial pulpotomy and show no difference between these treatments (43).

Conversely Asgary in 2014 found a higher percentage of success for pulpotomy (100%) than for DPC (96.4%) (34).

(Annex 5 & 6 – Analysis of selected studies).

4.2.4. Pulpotomy

Traditionally, pulpotomy is performed on temporary teeth or immature permanent teeth that present with deep decay and whose removal will lead to pulpal exposure. These teeth should show Baume category I or II symptomatology (11). In addition, a tooth with DPC that is impossible to place, due to endless bleeding, may be subjected to a pulpotomy. Finally, if retention is sought for prosthetic reasons, partial pulpectomy may be preferred to DPC (34,44). There are several types of pulpotomy: miniature pulpotomy (MP), cameral pulpotomy and partial pulpectomy. Their implementation varies depending on the depth of pulp eviction that is necessary; itself depends on the degree of inflammation of the pulp (45).

Experts believe that the success of pulpotomy is correlated with several factors (17):

- The fact that the remaining pulp may be either non-inflamed or able to heal
- Control of bleeding
- The application of a biocompatible material

- The presence of a watertight seal with the restoration to prevent bacterial infiltration

In 2013, Barngkgei (11,32) extends the indications for pulpotomy to mature symptomatic permanent teeth with pulp exposure of iatrogenic origin (following caries curettage) or caries origin. The number of subjects is low, but the results are interesting: out of the 11 teeth concerned, all are asymptomatic after about 30.5 months. They respond positively to pulpal vitality tests and do not present an apical lesion.

Powell, in 2012 (44) studied partial and total pulpotomy and reported 3-year success rates of 99.4% without revealing a significant difference between the use of Biodentine™ and MTA as pulp protection.

Finally, Asgary in 2014 (46) showed a 100% success rate on 38 permanent teeth showing signs of irreversible pulpitis, using miniature pulpotomy and cameral pulpotomy.

4.2.5. Discussion

Complete caries removal techniques in deep caries no longer seem to be relevant, as does the need to reopen the cavity after partial curettage during IPC (stepwise method). Current studies focus more on safe removal of caries when pulpal exposure is feared. A large number of selected studies deal with caries curettage, but the notion of depth of eviction is still unclear, as is the life expectancy of these treatments.

Avoiding RCT preserves the structure and vitality of the tooth, therefore its longevity. All these treatments require a certain rigor and an important implementation protocol (isolation of the cavity, complete peripheral caries eviction, seal material), which are essential for therapeutic success. The current

concept of conservative dentistry leans on a step-by-step care and reasoned removal, but few practitioners implement these recommendations and prefer to undertake RCT, in case of deep decay, to prevent pain.

Although VPT techniques bring promising results, Bjørndal points out that the very idea of leaving infected tissue under a restoration will take a long time to become established (11).

The different randomized clinical studies have shown the quality and longevity of capping techniques in patients with reversible and irreversible pulpitis on mature permanent teeth. To summarize, in the presence of a deep carious lesion (involvement of 2/3 or even 3/4 of the dentin) and if the tooth has a reversible pulpal involvement (categories I to II of Baume), it is recommended to carry out a partial curettage. Following this curettage, two options arise: either the thickness of the juxta-pulp residual dentin is less than 0.5 mm and, in this case, it is preferable to implement an IPC; or the residual dentin is greater than 0.5 mm and a simple composite restoration will allow to stop the carious lesion and heal the pulp. If the lesion is deeper and the pulp invasion is inevitable but minimal, it will be necessary to put in place a DPC with a pulp protection. Finally, if the pulp involvement is more advanced, a cameral pulpotomy is still possible. A regular radiological and/or clinical check-up is essential to control the conservation of the vitality of the treated tooth.

There are still too few comparative studies between the different treatments. Due to the short follow-up period in most studies and the high risk of bias, long-term clinical trials are still needed to evaluate the most effective intervention. Moreover, the majority of these studies did not include a control group, an element to be taken into account when interpreting the results (31).

4.3. Clinical outcomes of different materials

In this part, different materials – such as CaOH, MTA, Biodentine, Glass Ionomer Cement (GIC) – will be compared in the case of their usage in the different techniques (IPC, DPC, pulpotomy).

4.3.1. <u>According to IPC</u>

Regarding the IPC technique, the study by Leye Benoist in 2012 (30) showed at 3 months a success rate for MTA of 93.1% compared to 73.3% for CaOH. While Koc Vural in 2017 (15) showed that there was no significant difference for the vitality of the pulp between the two capping materials (MTA, CaOH) at 6, 12 or 24 months after treatment.

In 2016, Mathur (47) conducted a study that showed that MTA, CaOH and GIC give a success rate of 96.85% with results similar to radiography.

Finally, in 2019, Hashem (48) reports that Biodentine™ and the Glass Ionomer Cement (GIC) – of the Fuji IX™ type – give excellent results and no difference was observed between the periods of 12 and 24 months on the radiographic plan.

(Annex 7 – Table of studies comparing IPC materials).

4.3.2. <u>According to DPC</u>

Different materials have been used successfully in DPC, and according to Parinyaprom (49), Biodentine™ was not inferior to MTA with an overall success rate of 96.4%. The study by Brizuela (42), comparing MTA and CaOH showed that there were no statistically significant differences between the materials studied at the different time intervals (3 months, 6 months and 1 year).

The work of Katge (50), comparing Biodentine™ and MTA on 50 patients with asymptomatic caries lesions, showed an overall success rate of 100% at

baseline, at 6 and 12 months of follow-up on the basis of clinical and radiographic parameters.

Nowicka (51) reported that the repair dentin formed in the CaOH, MTA and Biodentine™ groups was significantly greater than that formed in the Single Bond™ Universal group in terms of thickness and volume. It showed that the universal adhesive system exhibited histological signs of pulpitis and a significantly lower thin mineralized tissue layer compared to the CaOH. They concluded that Single Bond™ Universal is unsuitable for DPC.

In a study, AlShwaimi (52) stated that DPC with MTA would lead to a good pulp response with less inflammation and the formation of a thicker dentinal bridge at 8 weeks.

(Annex 8 – Table of studies comparing DPC materials).

4.3.3. According to pulpotomy

The results of the work of Taha (53) on partial pulpotomy using MTA and CaOH on mature permanent molars with irreversible pulpitis showed a higher success rate in the MTA group than that of CaOH. The difference was statistically significant after two years (83% vs. 55%) at one year; (85% vs 43%) at 2 years.

The study by Kang (54) showed that teeth treated by partial pulpotomy with three types of MTA materials gave a high success rate with no significant difference in results (ProRoot MTA: 96.0%, OrthoMTA: 92.8%, RetroMTA: 96.0%).

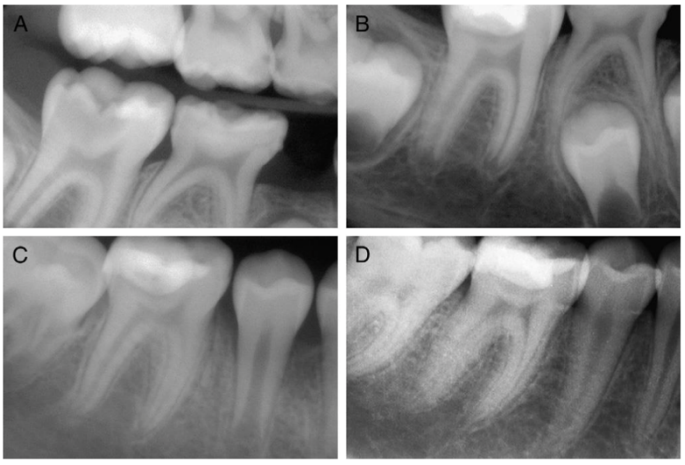
Bakhtiar (55) reported that Biodentine™ has also given excellent results. According to Chailertvanitkul (56), the failure rate of partial pulpotomy was related to the pulpal exposure area. Exposure of less than 5mm was more favorable for success than exposure of more than 5mm.

Taha (57) also evaluated complete pulpotomy with Biodentine™ on symptomatic permanent teeth with pulpal exposure. One tooth showed signs of internal root resorption after one year, with an overall success rate of 95% (19/20 teeth).

(Annex 9 – Table of studies comparing materials for pulpotomy).

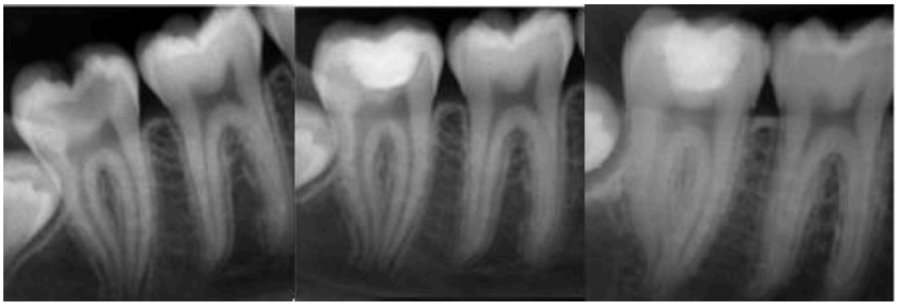
Research in dentistry is currently turning to new materials that are not only biocompatible but also bioactive, which could allow pulp tissue regeneration and ensure its sustainability. Indeed, the current enthusiasm for micro-invasive dentistry is not trivial and modern dentistry realizes that beyond mechanics there is biology and that it is the key to a healthy oral cavity.

4.4. Cases selection



A: tooth 46 with a deep cavity. Before treatment.
B: tooth 46 treated by IPT. 1 week after the treatment.
C: 2.5 years after the treatment, we can see that apices have closed.
D: mature permanent 46, 5 years after the treatment.

Clinical case of a deep carious lesion treated by IPT (19)*. Patient is 6.5 years old and the treated tooth is the right first mandibular molar.*

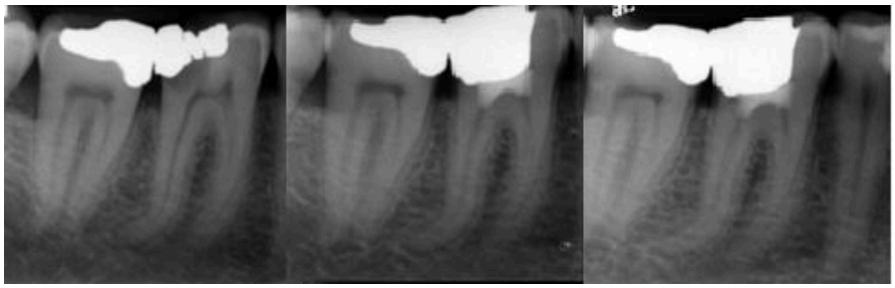


A: tooth 47 with a carious lesion. Before treatment.
B: tooth 47 treated by IPC. Right after treatment.
C: control radiography 1 year after treatment.

Clinical case of a deep carious lesion treated by IPC (40)*. The treated tooth is the right second mandibular molar.*

A: tooth 47 with a deep caries. Before treatment.
B: tooth 47 treated by DPC. Right after treatment.
C: control radiography 1 year after treatment.

Clinical case of a deep carious lesion treated by DPC (11)*. The treated tooth is the right second mandibular molar.*



A: tooth 47 with a deep caries. Before treatment.
B: tooth 47 treated by pulpotomy. Right after treatment.
C: control radiography 1 year after treatment.

Clinical case of a deep carious lesion treated by pulpotomy (11)*. The treated tooth is the right second mandibular molar.*

5. CONCLUSIONS

Pulp capping techniques are the best options as a therapy for preserving pulp vitality, scientifically enrolled as a part of an oral medicine that aims to be less invasive and more conservative. Indeed, maintaining and preserving pulp vitality, unlike a RCT, gives the tooth a chance to continue to defend itself against attacks and avoid becoming weak and therefore fracture. The practitioner should make this a primary concern in a daily practice.

Even though studies have shown that the type of material had no influence on the success of the treatments, Biodentine™ stands out and is on its ways of becoming the material of choice with promising results in the studies, although there are not enough for the moment.

6. RESPONSIBILITY

On an economic level, VPT is very advantageous for many reasons. The first one is that the cost for a VPT, although the material used could be expensive, is always less than doing a RCT. It goes with everything that VPT has to offer, meaning keeping the tooth vital, therefore reducing the risk of fracture, thus avoiding treatments like extractions, which inevitably reduce the costs not only of the previous procedures but also of further aesthetic treatments that could be implants if the tooth is missing. Moreover, it takes a lot of time to do a RCT, especially in multiradicular teeth like molars, which is not the case when doing VPT, then reducing the time of chair for both patient and practitioner, indirectly diminishing the total costs because the dentist will be able to see more patient in the same amount of time.

From a social point of view, since few years now, dentistry tends to be more and more conservative, following the principle of always trying to preserve a tooth. This mentality is on the rise with many new studies concerning techniques like VPT, but also discovery of new materials that are not only biocompatible but also bioactive and will lead conservative techniques at the top. There is also the psychological dimension to consider, as patients pay more and more attention to their looks, their aesthetic aspects, beginning with their teeth and a young patient will always feel better knowing that he has sound teeth than endodontically treated teeth that might tend to extraction and leave a space in the mouth that has to be filled with prosthetics.

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8. ANNEXES

Annex 1 – Table of studies comparing post-operative pain reduction in VPT & RCT.

Author	Sample	Parameters	Type of analysis	Comparison
Eren, 2018 (11)	N=66	Severe pain in molars Irreversible pulpitis Adults	Experimental randomized clinical trial	Pulpotomy/partial pulpectomy & RCT
Cousson, 2014 (24)	N=646	Any patient with one RCT Permanent dentition	Observational cohort study	Pulpotomy & RCT
Asgary, 2015 (25)	N=407	Irreversible pulpitis in molars Permanent dentition	Experimental randomized clinical trial	VPT & RCT
Galani, 2017 (26)	N=54	Irreversible pulpitis Mandibular molars Healthy periodontium Permanent dentition	Experimental randomized clinical trial	Pulpotomy & RCT

Annex 2 – Table of selected studies for IPT.

Author	Subject	Type of study	Parameters	Sample
Bjørndal, 2010 (27)	Stepwise VS. Complete curettage	Controlled clinical trial	- Permanent dentition - Adults with reversible pulpitis	314 patients
Gruythuysen, 2010 (34)	IPT	Clinical retrospective study	- Temporal and permanent dentitions - Patients with reversible pulpitis	86 temporal teeth, 34 permanent teeth
Maltz, 2012 (40)	Partial curettage VS. Stepwise	Controlled clinical trial	- Permanent dentition - Adults with reversible pulpitis	213 teeth
Maltz, 2012 (35)	Partial curettage VS. Complete curettage	Prospective microbiologic study	- Permanent dentition - Patients between 15 and 50 yo with reversible pulpitis	87 patients, 90 teeth
Orhan, 2010 (36)	IPT VS. complete curettage	Controlled clinical trial	- Both dentitions - Patients between 4 and 15 yo	154 teeth

Annex 3 – Analysis of selected studies for IPT.

Author	Results	Follow-up duration	Conclusion of the study
Bjørndal, 2010	- Stepwise success: 74.1% - Success complete curettage: 62.4%	477 days	SW technique decreases the risk of pulpal exposure compared to complete curettage
Gruythuysen, 2010	- Success for temporal teeth: 96% - Success for permanent teeth: 93%	3 years	Important success of IPT over 3 years follow-up
Maltz, 2012	- Partial curettage success: 91% - Success Stepwise: 69%	3 years	Re-opening the cavity is not necessary to preserve pulpal vitality
Maltz, 2012	Number of bacteria present after curettage are superior than those after sealed cavity	-	Complete removal of all carious dentin is not necessary if the restauration is perfectly sealed
Orhan, 2010	- Success for 100% after 1st visit, 98% after 2nd visit - 95% for complete curettage	1 year	Partial curettage results in a significantly inferior rate of pulpal exposure compared to complete curettage

Annex 4 – Classification of Baume.

Categories	Pulp vitality	Symptomatology	Treatment
I	Vital	No	Capping
II	Vital	Yes	Capping or pulpotomy
III	Vital	Yes	RCT
IV	Necrotic	-	RCT

The classification of Baume is a symptomatologic classification for therapeutic purposes.

Annex 5 – Table of selected studies for DPC.

Author	Subject	Type of study	Parameters	Sample
Bjørndal, 2010 (39)	DPC VS. Pulpotomy	Controlled randomized clinical trial	- Permanent dentition - Adults with reversible pulpitis	58 patients
Asgary, 2014 (34)	DPC	Clinical trial	- Permanent dentition - Irreversible pulpitis	93 patients, 93 teeth
Dammaschke, 2010 (11)	DPC	Controlled randomized clinical trial	- Permanent dentition - Patients between 16 and 72 yo with reversible pulpitis	248 teeth

Annex 6 – Analysis of selected studies for DPC.

Author	Results	Follow-up duration	Conclusion of the study
Bjørndal, 2010	- DPC success: 31.8% - Pulpotomy success: 34.5%	477 days	No significative difference between DPC and pulpotomy
Asgary, 2014	DPC success: 96.4%	12.3 months	All vital pulp treatments could be considered a success under ideal conditions
Dammaschke, 2010	Mean success: 76.3% after 13.3 years of evolution, variable according to final restauration	6.1 years	DPC must be avoided in teeth with spontaneous pain or discomfort. The cavities should be restored with a bacteria-proof filling material immediately after the capping. Costly restorations should not be considered until 2 years after pulp capping.

Annex 7 – Table of studies comparing IPC materials.

Author	Type of study	Results
Koc Vural, 2017 (43)	Randomized clinical trial	4 teeth coated with CaOH and 2 teeth coated with MTA received emergency RCT due to symptoms of irreversible pulpitis, which has been clinically and/or radiographically established. There were no significant differences in pulp vitality between the two pulp capping agents at six, 12 or 24 months after treatment.
Mathur, 2016 (47)	Randomized clinical trial	The success rate for IPC was 96.85%. A significant difference was obtained in the mean thickness of the restorative dentin at the immediate postoperative values and at 6 months postoperative in the 3 groups. Similar significant results were obtained for the radiodensity of the barrier formed. MTA, CaOH and GIC have also been shown to be suitable for IPC.
Hashem, 2018 (48)	Randomized clinical trial	At 24 months, 15 teeth had failed to maintain their vitality (6 Biodentine™, 9 Fuji IX™). The clinical success rate for IPC for both materials was 72% and is related to the intensity of symptoms of reversible pulpitis. There were no differences between the 12th and 24th month periods radiographically and in the integrity of the composite restorations overlying Biodentine™ compared to Fuji IX™.

Annex 8 – Table of studies comparing DPC materials.

Author	Type of study	Results
Parinyaprom, 2018 (49)	Comparative study	55 patients (mean age, 10 ± 2 years), 27 treated with ProRoot MTA and 28 with BiodentineTM, were included in the analysis. At a mean follow-up of 18.9 ± 12.9 months, the success rate was 92.6% with ProRoot MTA and 96.4% with Biodentine™. Biodentine™ was not inferior to ProRoot MTA. No significant difference was observed between them. Gray discoloration was only seen with ProRoot MTA (55%).
Brizuela, 2017 (42)	Randomized clinical trial	At the 1-week follow-up examination, patients showed 100% clinical success. At 3 months, there was 1 failure in the CaOH group. At 6 months, there were 4 new failures (1 in the CaOH group and 3 in the MTA group). At 1 year, there was another failure in the CaOH group. There were no statistically significant differences between the experimental groups.
Katge, 2017 (50)	Comparative study	The study reported a 100% success rate with Biodentine™ and MTA at baseline, at 6 and 12 months, based on clinical and radiographic parameters. There was no statistically significant difference. Radiographically, dentinal bridge formation was not evident in the 2 groups at baseline but was after 6 and 12 months of follow-up. And still no significant difference.
Nowicka, 2016 (51)	Histological and clinical study	The clinical phase was asymptomatic for Single Bond Universal patients. Patients in the CaOH group reported symptoms of mild pain, although histological examination revealed that dentinal bridges with or without limited pulpitis had started to form in each tooth.
AlShwaimi, 2016 (52)	Histological and clinical study	Betamethasone/gentamicin (BG) cream and MTA both caused dentinal bridges to form. The inflammation was acute in all groups; no statistically significant difference in the distribution of inflammatory cells was found between the groups. Pulp abscesses and/or necrosis were observed more often in teeth capped with BG than in those capped with MTA.

Annex 9 – Table of studies comparing materials for pulpotomy.

Author	Type of study	Results
Taha, 2017 (53)	Comparative study	Failure occurred on 4 teeth after treatment. At 1 year, the MTA showed a greater tendency to succeed compared to the CaOH group, and the difference was statistically significant after 2 years (83% vs. 55% at 1 year; 85 % vs. 43% at 2 years).
Kang, 2017 (54)	Comparative study	Partial pulpotomy maintained a high success rate for up to 1 year with no significant difference in results treated with 3 MTA materials: ProRoot MTA 96%; Ortho MTA 92.8%; Retro MTA 96%.
Bakhtiar, 2017 (55)	Clinical trial	Clinical examination showed no sensitivity to heat, cold or palpation in the ProRoot MTA and Biodentine™ groups. Inflammation was absent with all materials at 8 weeks. Normal pulp organization was observed in 33.33% of teeth in the ProRoot MTA group and 66.67% in the Biodentine™ group. The Biodentine™ group showed complete dentin bridge formation in all teeth, while this rate was 56% in ProRoot MTA group.
Chailertvanitkul, 2014 (56)	Comparative study	The failure rate of partial pulpotomy was related to the pulpal exposure area.
Taha, 2018 (57)	Clinical study	2 days after treatment, all patients reported complete pain relief. We had clinical success at 6 months and 1 year. Radiographically, the immature roots showed closed tips; the formation of a dentinal bridge was observed in 5/20 teeth. 7/7 teeth with preoperative periapical rarefaction showed signs of healing; 1 tooth showed signs of internal root resorption at 1 year, with an overall success rate of 95% (19/20).

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REVIEW

Demineralization–remineralization dynamics in teeth and bone

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Abstract: Biomineralization is a dynamic, complex, lifelong process by which living organisms control precipitations of inorganic nanocrystals within organic matrices to form unique hybrid biological tissues, for example, enamel, dentin, cementum, and bone. Understanding the process of mineral deposition is important for the development of treatments for mineralization-related diseases and also for the innovation and development of scaffolds. This review provides a thorough overview of the up-to-date information on the theories describing the possible mechanisms and the factors implicated as agonists and antagonists of mineralization. Then, the role of calcium and phosphate ions in the maintenance of teeth and bone health is described. Throughout the life, teeth and bone are at risk of demineralization, with particular emphasis on teeth, due to their anatomical arrangement and location. Teeth are exposed to food, drink, and the microbiota of the mouth; therefore, they have developed a high resistance to localized demineralization that is unmatched by bone. The mechanisms by which demineralization–remineralization process occurs in both teeth and bone and the new therapies/technologies that reverse demineralization or boost remineralization are also scrupulously discussed. Technologies discussed include composites with nano- and micron-sized inorganic minerals that can mimic mechanical properties of the tooth and bone in addition to promoting more natural repair of surrounding tissues. Turning these new technologies to products and practices would improve health care worldwide.

Keywords: demineralization, remineralization, teeth, bone and calcium phosphates

Introduction

Enamel, dentin, cementum, and bone are natural composites of both organic and inorganic components. Bone, cementum, and dentin are specialized connective tissues, while enamel has an ectodermal origin. For the specialized connective tissues (bone, cementum, and dentin), collagen type I constitutes ~90% of their organic component;[1,2] noncollagenous proteins form the remaining. On the other hand, enamel has little or no collagen, and its organic matrix is made up of noncollagenous protein, which is 90% amelogenin.[3] The inorganic component of these hard tissues consists of biological apatite, $Ca_{10}(PO_4)_6(OH)_2$. Enamel has more inorganic content (~90% prismatic crystals) than dentin and bone (~70%) and cementum (45%). The unit cell of biological apatite is hexagonal in shape; repetitions of the unit cells produce crystals of various sizes. In dentin, the crystals are plate like of 50 nm length, 20 nm width, and 2–5 nm thickness.[4] In bone, the crystals are known to be ~2–6 nm thick, 30–50 nm wide, and 60–100 nm long.[5] However, they are bigger and highly oriented in enamel than in bone and dentin, making it the hardest tissue in the body. Due to the presence of a variety of substitutions and vacancies within the biological apatite, its calcium–phosphate ratio is different from that of stoichiometric hydroxyapatite (HA, 1.67). Enamel apatite,

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REVIEW

Disclosing the physiology of pulp tissue for vital pulp therapy

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Abstract

da Rosa WLO, Piva E, da Silva AF. Disclosing the physiology of pulp tissue for vital pulp therapy. *International Endodontic Journal*, **51**, 829–846, 2018.

The discovery that dentine is a reservoir of bioactive molecules that can be recruited on demand has attracted efforts to develop new protocols and materials for vital pulp therapy (VPT). The noncollagenous proteins (NCPs) present in the dentine extracellular matrix (ECM) include growth factors (TGF-β1, BMP-7, FGF-2, IGF-1 and IGF-2, NGF and GDNF), extracellular matrix molecules (DSP, DPP, BSP, DMP-1 and DSPP) and both anti-inflammatory and pro-inflammatory chemokines and cytokines (TNF-α, IL-1, IL-6 and IL-10). Molecules such as DSP and DPP are mainly expressed by odontoblasts, and they are cleaved products from dentine sialophosphoprotein (DSPP). Some molecules, such as TGF-β1, specifically interact with decorin/biglycan in dentine. Although TGF-β1 increases the expression and secretion of NGF in human pulp cells, NGF induces mineralization and increases the expression of DSPP and DMP-1. Furthermore, GDNF may act as a cell survival factor and mitogen during tooth injury and repair. Pulp capping materials, such as MTA and calcium hydroxide, can solubilize bioactive dentine molecules (TGF-β1, NGF and GDNF) that stimulate tertiary dentinogenesis. The binding of these signalling molecules leads to activation of several signalling transduction pathways involved in dentinogenesis, odontoblast differentiation and inflammatory responses, such as the p38 MAPK, NF-kβ and Wnt/β-catenin signalling pathways. Understanding the cascade of cellular and molecular events underlying the repair and regeneration processes provides a reasonable new approach to VPT through a targeted interaction between tooth tissue and bioactive molecules.

Keywords: dentinogenesis, molecular biology, protein expression, pulp biology, signal transduction.

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Introduction

Pulp tissue can be affected as the result of deep caries lesions and accidental trauma or by preparation techniques used during the restoration of teeth affected by carious lesions (Mattos *et al.* 2014). Thus, protection of the pulp by applying capping agents directly or indirectly on pulp tissue is called vital pulp therapies (VPTs) (Da Rosa *et al.* 2017).

In recent years, with the progress of regenerative and molecular approaches, it is known that the efficacy of direct and indirect pulp capping might be affected by the biomaterials used and their biological properties. Some studies have suggested that the effect of using calcium hydroxide or glass–ionomer cement on dentine caries is not superior to the use of an inert material (such as wax; Corralo & Maltz 2013), in indirect pulp capping of primary (Marchi *et al.* 2006, Casagrande *et al.* 2010, Schwendicke *et al.* 2015) or permanent teeth (Baratieri *et al.* 2002, Whitworth *et al.* 2005, Wegehaupt *et al.* 2009, Pereira *et al.*

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Could the application of bioactive molecules improve vital pulp therapy success? A systematic review

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IEJ
Iranian Endodontic Journal

New Approaches in Vital Pulp Therapy in Permanent Teeth

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ABSTRACT

Vitality of dental pulp is essential for long-term tooth survival. The aim of vital pulp therapy is to maintain healthy pulp tissue by eliminating bacteria from the dentin-pulp complex. There are several different treatment options for vital pulp therapy in extensively decayed or traumatized teeth. Pulp capping or pulpotomy procedures rely upon an accurate assessment of the pulp status, and careful management of the remaining pulp tissue. The purpose of this review is to provide an overview of new approaches in vital pulp therapy in permanent teeth.

Keywords: Cvek Pulpotomy; Partial Pulpotomy; Permanent Teeth; Pulp Capping; Vital Pulp Therapy

Introduction

Vital pulp therapy (VPT) is defined as a treatment which aims to preserve and maintain pulp tissue that has been compromised but not destroyed by caries, trauma, or restorative procedures in a healthy state. This is particularly important in the young adult tooth with incomplete apical root development. It has been recommended that VPT should be performed only in young patients because of the high healing capacity of pulp tissue compared to older patients [1, 2]. Since the evidence regarding the effect of the patients' age and the status of the root apex on the outcome of VPT did not indicate that this treatment could not be performed successfully in old patients, and based on the premise of innate capacity of pulp tissue for repair in the absence of microbial contamination, preservation of the pulpally involved permanent tooth is also considered [3].

Another important benefit for preservation of vital pulp is the protective resistance to mastication forces compared with a root-canal-filled tooth [4]. It is reported that the survival rate of endodontically treated teeth is not as good as vital teeth especially in molars [5]. Therefore, the vital pulp should be preserved if possible.

One of the most important issues in VPT is the status of the pulp tissue. The traditional school of thought is that VPT should only be carried out in teeth with signs and symptoms of reversible pulpitis [6]. The problem is how we can accurately assess the status of the pulp. The clinical signs and symptoms such as sensibility and pain testing do not precisely reflect the pulp condition [7-9]. Furthermore, several studies have reported successful treatment outcome in vital teeth with curiously exposed pulp with signs and symptoms of irreversible pulpitis and periapical lesions [10-13]. The degree of pulpal bleeding may be a better indicator of pulpal inflammatory status [10]. Increased bleeding on exposure site that is difficult to stop, suggest that the inflammatory response extends deeper into the pulp tissue and the treatment procedure should be modified, for example by shifting from direct pulp cap to partial pulpotomy.

Additionally, other factors may affect the success of VPT. The presence of an adequate *blood supply* is required for the maintenance of the pulp vitality [14]. In addition, the presence of a *healthy periodontium* is necessary for success of VPT, and teeth with moderate to severe periodontal disease are not suitable candidates for the treatment [15].

Suitable candidates for VPT include teeth in which an appropriate *coronal seal* can be provided. The prognosis of VPT is significantly reduced in cases with inadequate coronal seal and subsequent bacterial microleakage [16].

Control of hemorrhage is also necessary for the success of VPT [10]. Various options are available for the achievement of pulp hemostasis such as mechanical pressure using a sterile cotton pellet which may be soaked

Dental Research Journal

Review Article

Outcomes of vital pulp therapy in permanent teeth with different medicaments based on review of the literature

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ABSTRACT

Vital pulp therapy (VPT) is a biologic and conservative treatment modality to preserve the vitality and function of the coronal or remaining radicular pulp tissue in vital permanent teeth. A search was conducted via the Cochrane database, PubMed, MEDLINE, and Ovid for any articles with the criteria for "pulp-capping," or "pulp-capping materials" and "VPT outcomes" from 1978 to mid 2014. All articles were evaluated and the valid papers were selected. The outcomes of various VPT techniques, including indirect pulp treatment, direct pulp treatment, partial pulpotomy, and complete pulpotomy in vital permanent teeth were extracted. Although various studies have different research approach, most studies noted a favorable treatment outcome. Mineral trioxide aggregate (MTA) appears to be more effective than calcium hydroxide ($Ca(OH)_2$) for maintaining long-term pulp vitality after indirect and direct pulp-capping. However, it seems that the success rate for partial pulpotomy and pulpotomy with $Ca(OH)_2$ is similar to MTA.

Key Words: Dental cements, calcium hydroxide, permanent dentition, mineral trioxide aggregate, root canal therapies

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INTRODUCTION

The aim of treatment after pulp exposure is to promote the pulp tissue healing and facilitate the formation of reparative dentin in order to preserve the pulp vitality and health.[1] Vital pulp therapy (VPT) procedures involve removal of local irritants and placement of a protective material directly or indirectly over the pulp.[2] These treatments must be followed by an overlying tight-sealed restoration to decrease bacterial leakage from the restoration-dentin interface. VPT is performed to treat reversible pulpal injury in order to promote root development, apical closure and accomplish complete root canal therapy.[1,3-5]

There are controversies within the studies on VPT regarding judgment criteria and pulpal status at the time of treatment, optimal technique and treatment outcomes.[1,3,5] There is no consensus as to the best therapeutic technique and comprehensible diagnostic indications for the management of caries-exposed permanent teeth.[1,3,5] No long-term data regarding the outcome and the survival rate of VPT is available, either.[2] The purpose of this paper was to review

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Wound Repair and Regeneration

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Key Words
Angiogenesis · Epithelialization · Granulation tissue · Inflammation · Scarring

Abstract
The skin is the biggest organ of the human being and has many functions. Therefore, the healing of a skin wound displays an extraordinary mechanism of cascading cellular functions which is unique in nature. As healing and regeneration processes take place in all parts of the human body, this review focuses on the healing processes of the skin and highlights the classical wound healing phases. While regeneration describes the specific substitution of the tissue, i.e. the superficial epidermis, mucosa or fetal skin, skin repair displays an unspecific form of healing in which the wound heals by fibrosis and scar formation. The first stage of acute wound healing is dedicated to hemostasis and the formation of a provisional wound matrix, which occurs immediately after injury and is completed after some hours. Furthermore, this phase initiates the inflammatory process. The inflammatory phase of the wound healing cascade gets activated during the coagulation phase and can roughly be divided into an early phase with neutrophil recruitment and a late phase with the appearance and transformation of monocytes. In the phase of proliferation the main focus of the healing process lies in the recovering of the wound surface, the formation of granulation tissue and the restoration of the vascular network. Therefore, next to the immigration of local fibroblasts along the fibrin network and the beginning of reepithelialization from the wound edges, neovascularization and angiogenesis get activated by capillary sprouting. The formation of granulation tissue stops through apoptosis of the cells, characterizing a mature wound as avascular as well as acellular. During the maturation of the wound the components of the extracellular matrix undergo certain changes. The physiological endpoint of mammalian wound repair displays the formation of a scar, which is directly linked to the extent of the inflammatory process throughout wound healing.

Introduction

An intact outer sheath is one of the most important features from simple bacteria to complex multicellular organisms. Furthermore, the ability of organisms to repair or regenerate tissues in order to restore organ functions has been and still is a selective advantage and a survival factor in nature. As most of the organisms are subject to a continuous renewal process throughout life, the ability to heal is developed differently throughout diverse species from simple tissue repair to the regenera-

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Regenerative Endodontic Treatment of Permanent Teeth after Completion of Root Development: A Report of Two Cases

Khimiya Paryani, DDS, and Sahng G. Kim, DDS, MS

Abstract

Introduction: Clinical regenerative endodontic treatment has been focused on immature necrotic teeth, but it should be extended to mature teeth as an alternative to conventional endodontic treatment. There have been no clinical reports to attempt to revascularize pulp in the entire root canals of mature necrotic teeth. The present report describes the treatment of mature, necrotic, permanent incisors with apical periodontitis by using regenerative endodontic therapy. **Methods:** In this case report, modified regenerative endodontic procedures were used to enhance the probability of pulp revasuclarization in mature necrotic teeth. At the first appointment, the root canals were mechanically instrumented to the apices with a large apical size by using the step-back technique and irrigated copiously with antimicrobial solution. Intracanal medicaments (calcium hydroxide or ciprofloxacin) were placed in the root canals. At the following appointment, the root canals were irrigated with antimicrobial solution, and bleeding was induced into the root canals by passing hand files beyond apices. Collagen membranes were placed in the canals as a matrix against which mineral trioxide aggregate was placed. Glass ionomer was used to restore the teeth. The resolution of apical radiolucency and regression of clinical signs and symptoms were observed at recall appointments. **Conclusions:** The present report presents modified regenerative endodontic procedures for mature necrotic permanent teeth. Further clinical studies with a large number of cases are needed to investigate the outcome of regenerative endodontic therapy for mature necrotic teeth. *(J Endod 2013;■:1–6)*

Key Words

Mature tooth, pulp regeneration, pulp revascularization, pulp revitalization, regenerative endodontics

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Advances in the field of regenerative endodontics and tissue engineering have allowed clinicians to perform a therapy called pulpal regeneration, which was adopted as a procedure code by the American Dental Association in January 2011 (1). The efficacy of this regenerative procedure in immature necrotic teeth has been demonstrated in numerous clinical studies, most of which are, however, case reports or case series. Since earlier work by Ostby (2) and Nygaard-Ostby and Hjortdal (3), there have been numerous attempts to regenerate pulp tissues in teeth. Irrespective of varying therapeutic approaches, pulp regeneration therapy aims to restore the pulp-dentin complex in the root canal system. Conceptually, pulp regeneration can be defined as revascularization, restoration of odontoblastic layers lining the dentin surface, and innervation (4).

Clinical regenerative endodontic procedures have been focused on immature necrotic teeth because they are anticipated to have a greater chance of pulp tissue regeneration on the basis of the following biological reasons. Immature teeth with open apices allow more stem/progenitor cells to migrate into root canals. Moreover, stem cells of the apical papilla (SCAP) found near immature root apices have been shown to possess a great regeneration potential in pulp regeneration (5, 6). Clinically, the thickening and lengthening of immature roots after regenerative endodontic therapy might strengthen immature teeth that are susceptible to fracture.

The indication and scope of regenerative endodontic procedures are currently limited to immature teeth but should be extended to mature teeth as an alternative to conventional endodontic treatment. From the perspective of tissue engineering, pulp regeneration in mature teeth offers the following advantages. Reconstitution of the neurovascular system in root canals by pulp regeneration will provide pulp tissues with an immune system, which will function as the first line of defense against microbial challenge. The gain of nerve function in regenerated pulp tissues will provide an alarm system during the tissue injury and protect the pulp from further damage. The restoration of the pulp-dentin complex may be achieved after regenerative endodontic therapy. In addition to pulp regeneration, dentin may be deposited along the root canal walls that had been lost during mechanical instrumentation after regenerative therapy by using tissue-engineering approaches (7), although the dentin deposition has not been consistently demonstrated (8).

Regenerative endodontic therapy in mature teeth will likely encounter more challenges than in immature teeth. Less stem/progenitor cells in mature teeth and narrower apical pathways for stem/progenitor cell migration will be major limitations, together with greater difficulty in disinfecting root canals in mature teeth. Until now, there has been no reported clinical case to regenerate or revascularize dental pulp in necrotic, mature human teeth since reports by Ostby (2) and Nygaard-Ostby and Hjortdal (3), where partial pulp regeneration was attempted with root canal filling short of root apices. The present report describes the treatment of mature, necrotic, permanent incisors with apical periodontitis by using regenerative endodontic therapy.

Case Report

Case 1

A 14-year-old girl presented with her mother to the postgraduate endodontic clinic on August 5, 2010 with a chief complaint of pain on her upper front tooth for the last 3

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Aust Endod J 2019

LITERATURE REVIEW

Vital pulp therapy of mature permanent teeth with irreversible pulpitis from the perspective of pulp biology

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Keywords
irreversible pulpitis, mature permanent teeth, pulp sensibility tests, root canal therapy, vital pulp therapy.

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Abstract

The American Association of Endodontists (AAE) Consensus Conference Recommended Diagnostic Terminology states that mature permanent teeth clinically diagnosed with irreversible pulpitis are treated with pulpectomy and root canal filling because inflamed vital pulp is not capable of healing. Histological studies have demonstrated that clinically diagnosed irreversible pulpitis does not involve the entire pulp. A recent International Endodontic Journal Editorial suggested clinical diagnosis of pulp disease should be reassessed because of the poor correlation between clinical symptoms and pulp sensibility testing and the actual histological status of the pulp. This review identified studies in a PubMed search that provide evidence for vital pulp therapy (VPT) of mature permanent teeth with irreversible pulpitis is predictable if correctly diagnosed and properly treated. A narrative review was undertaken to outline the correlation between the clinical symptoms/signs and pulp sensibility testing and the histological findings of the pulp. Treatment procedures for permanent teeth are outlined.

Introduction

Endodontics is not only concerned about clinical outcome but also the pathobiology of the pulpal–periapical disease. According to a systematic review of treatment of pulps in teeth affected by deep caries, it is not possible to determine whether an injured pulp caused by deep caries can be maintained or if it should be removed and replaced with a root canal filling because of the lack of well-controlled studies (1). This clearly indicates the difficulty in making an accurate diagnosis and treatment of pulp disease.

According to the American Association of Endodontists (AAE) Consensus Conference Recommended Diagnostic Terminology (2), the definition of irreversible pulpitis is that 'a clinical diagnosis based on subjective and objective findings indicating that the vital inflamed pulp is incapable of healing. Additional descriptors include lingering thermal pain, spontaneous pain, referred pain or no clinical symptoms but inflammation produced by caries, caries excavation and trauma'. Based on the AAE Guide to Clinical Endodontics (3), and American Academy of Pediatric Dentistry (AAPD) Guidelines on Pulp Therapy for Primary and Immature Permanent teeth (4), mature permanent teeth with irreversible pulpitis should be treated with nonsurgical root canal therapy. Vital pulp therapy (VPT) is primarily indicated for immature permanent teeth with reversible pulpitis caused by mechanical pulp exposure during carious excavation or operative procedure, or a traumatic pulp exposure of healthy teeth with minimal bacterial contamination (3,4). VPT includes indirect pulp treatment, direct pulp capping and pulpotomy (partial and complete) (3,4). Therefore, treatment of mature permanent teeth with irreversible pulpitis is not part of VPT. However, there are several recent studies of treatment of mature permanent teeth with irreversible pulpitis in the literature using the term 'vital pulp therapy'. In fact, VPT in these studies simply implies that the procedures used for direct pulp capping or pulpotomy of immature permanent teeth with reversible pulpitis can

BOOK REVIEW

Seltzer and Bender's Dental Pulp
Second edition
By Kenneth M. Hargreaves, Harold E. Goodis, Franklin Tay (editors)
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Spec Care Dentist 32(5): 223, 2012

I. B. Bender stated many years ago, when giving introductory remarks at a Pulp Biology conference: "Such a big issue about such a little tissue!" This book deals with all the issues and, therefore, is a complete and in-depth review of this important tissue. Overall, the approach is to examine the science and relate the science to clinical considerations and applications. For the reader who digests all this information, they would be very knowledgeable on the dental pulp. For the reader who is searching for specific aspects, that is possible, as well.

Because this review is published in the *Special Care in Dentistry* journal, the book was examined for the inclusion of information on this subject area. There were areas that dealt with this topic, but not to a great extent.

The three editors are credible, knowledgeable scientists, but also endodontic clinicians. Importantly, they formatted the book to include both scientific and clinical aspects. The editors enlisted 32 contributors, also noted scientist-clinicians. The publisher, Quintessence Publishing, produced an elegant product, as always. The paper is of high quality, the images are clear and well colored, and the text very readable.

There are 20 chapters. The first eight emphasize the basic science considerations. Chapters 9 through 12 deal with diseases of the pulp. The remaining chapters focus on clinical aspects and how pulp disease is produced from procedures, materials, and other etiologies, particularly iatrogenic. There are also chapters on pulp-related topics, such as resorption and pulpal-periodontal diseases.

Four chapters have relevance to the readers of this journal: Chapter 18 is titled "Aging and the Pulp"; Chapter 20 is "Interrelationship of Pulp and Systemic Disease"; Chapter 19 is "Differential Diagnosis of Toothache: Odontogenic versus Nonodontogenic Pain." The titles describe the content. Of particular interest is Chapter 5, which covers stem cells and regeneration. Although technologies are developing, there is promise in creating procedures to grow new tissues. Regeneration of pulp and other oral tissues may prove to be of benefit to special needs patients.

In summary, the central theme is stated in an entry in the Preface: "- the critical role that the pulp tissue plays in dental health." However, there is minimal focus, but significant information included that is directed to the clinician who treats the elderly and/or special needs patient.

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Outcomes of Different Vital Pulp Therapy Techniques on Symptomatic Permanent Teeth: A Case Series

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ABSTRACT

In modern endodontics, vital pulp therapy (VPT) has been considered an ultra-conservative treatment modality. Based on the level of pulp preservation, VPT includes stepwise excavation, indirect pulp capping (IDPC), direct pulp capping (DPC), miniature pulpotomy (MP), partial/Cvek pulpotomy and coronal/complete pulpotomy (CP). The present article reviews the treatment outcomes of 94 permanent teeth with irreversible pulpitis treated with either IDPC (*n*=28), DPC (*n*=28), MP (*n*=29) or CP (*n*=9) using calcium-enriched mixture (CEM) cement. After a mean follow-up time of 12.3 months, 93 treated teeth were radiographic/clinically successful; only one radiographic failure was observed in the DPC group.

Keywords: Calcium-Enriched Mixture; CEM Cement; Endodontic Treatment; Irreversible Pulpitis; Pulpotomy; Vital Pulp Therapy

Introduction

Although the value of a vital pulp in an immature permanent tooth is undeniable, its importance in a mature tooth cannot be overlooked [1]. Many authors have stated that the survival prognosis of endodontically treated teeth is not as good as teeth with vital pulps, which can be due to the loss of tooth structure as well as defensive mechanisms provided by the vital pulp such as tooth sensitivity and proprioception [2] as well as damping property [3].

There is no doubt that the biologic rationale for endodontic treatment is prevention or treatment of the only disease defined in this field, *i.e.* apical periodontitis (AP) [1, 4], which usually stems from a nonvital/infected pulp [1]. Therefore, it can be assumed that maintenance of the vital pulp ensures the prevention of AP and this is the paramount way of disease prevention [1, 4], keeping in mind that formation of AP around teeth with inflamed vital pulps is also possible [5].

There has been no universal agreement on the best treatment for cariously exposed vital pulps of permanent teeth [6]. While indication of mortal pulpectomy has several sensible reasons, vital pulpectomy gained general acceptance following several studies published before 1970s [4], with the rational being that the inflammation has probably reached a level where its elimination is not possible without removal of the entire pulp. The rationale for this treatment choice is first based on the unreliability of vital pulp therapy (VPT) on such teeth, which is challenged by recent high level of evidence (LoE) trials [7-10], and second the high probability for success in cases of optimally-performed root canal therapy (RCT) on vital teeth [6, 11]. However, financial considerations [12] or low dental IQ [8], result in some patients refusing the optimal treatment. In other words, in many developing or even developed countries many patients cannot or do not want to afford such an extensive treatment on a tooth that shows clinical signs of irreversible pulpitis and ask for its extraction which undoubtedly is not the correct and ethical alternative treatment plan [7, 8, 12]. The most important issue is the impossibility of determining the reversible or irreversible nature of the pulpitis as a histological term [13], merely based on clinical sign/symptoms such as degree/characteristic of pain as they often do not reflect the pulp condition [13].

VPT of adults' permanent dentition includes partial/miniature/coronal extirpation of the dental pulp (*aka.* pulpotomy) [14, 15] and covering the wound with biomaterials, or *in-situ* preservation of the whole pulp and its direct/indirect capping with the same biomaterials (*aka*. pulp capping) [16-18]. The ultimate goal of all these treatment modalities is preservation of the healthy portion of the pulp and therefore maintaining its healing ability [19, 20].

RESEARCH REPORTS
Biomaterials & Bioengineering

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Does Incomplete Caries Removal Reduce Strength of Restored Teeth?

ABSTRACT

Little information is available about whether the presence of residual caries beneath an occlusal restoration affects fracture strength of the tooth. This *in vitro* study tested the hypothesis that restored teeth after incomplete excavation have lower fracture strengths than restored teeth after complete excavation. Fourteen pairs of molars were randomly assigned to an experimental (incomplete excavation) or to a control group (complete excavation) and loaded vertically (after cyclic loading). Failure load and fracture mode were recorded. Restored teeth in the incomplete excavation group resulted in reduced fracture strength ($p < 0.001$) of the tooth-restoration complex (1276 N ± 626 N) compared with the control group (2768 N ± 710 N). Teeth in the complete excavation group all fractured vertically, while in the experimental group, cracks in the restoration were observed, characterized as 'ice-cracks'. The fracture strength of teeth restored over incomplete caries excavation was significantly reduced, possibly resulting in long-term clinical failure.

KEY WORDS: dental caries, excavation, fracture, stepwise, caries removal.

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INTRODUCTION

The role of operative intervention in the treatment of caries is changing. Caries progression can be stopped when carious tissue is sealed with a restoration (Handelman, 1991; Mertz-Fairhurst *et al*., 1998; Maltz *et al*., 2007). Clinical studies on the 'stepwise excavation' technique, in which final excavation is postponed and carious dentin is covered with a temporary restoration, revealed that at re-entry, both infected and affected dentin were darker, harder, and dryer and contained substantially less viable micro-organisms (Bjørndal *et al*., 1997; Bjørndal and Larson, 2000; Maltz *et al*., 2002). Even the one-session ART excavation approach revealed a substantial decrease in micro-organisms and increased mineral density in the remaining dentin over time (Massara *et al*., 2002; Santiago *et al*., 2005).

Leaving carious tissue on the axial floor in case of a deep lesion should be preferred over vigorous excavation, because incomplete caries removal leads to less pulpal damage, caries arrest, and acceptable short-term restoration longevity (Leksell *et al*., 1996; Ricketts *et al*., 2006; Maltz *et al*., 2007). As a result of caries arrest, tubular sclerosis and reactionary dentin are produced, reducing the permeability of remaining dentin (Kidd, 2004). Therefore, the suitability of traditional operative techniques of removing all infected/affected dentin is questioned (Kidd, 2004; Fejerskov and Kidd, 2008). Instead, the recommendation is to remove only carious tissues that cannot be remineralized (Kidd, 2004; Fejerskov and Kidd, 2008).

However, there is insufficient information about the long-term survival of restorations placed after incomplete caries removal. Composite restorations placed on top of soft carious tissue (infected dentin) showed a higher prevalence of clinical failures than sealed amalgam restorations with complete excavation (Mertz-Fairhurst *et al*., 1998). Some fractures of restorations placed over a residual layer of soft dentin occurred after 36-45 mos (Maltz *et al*., 2007). Leaving a layer of carious dentin may influence restoration strength in two ways. As we know, higher bond strengths are achieved when a restoration material is bonded to sound instead of carious dentin (Xie *et al*., 1996; Yoshiyama *et al*., 2002; Say *et al*., 2005). Second, carious dentin is softer and has a lower Young's modulus than sound dentin (Marshall *et al*., 2001; Zheng *et al*., 2003). Both factors may result in larger deformation of the tooth-restoration complex, leading to higher marginal stresses and increased susceptibility to fatigue failure. Thus, when soft carious tissue is left in the cavity before the tooth is restored, the fracture strength of the tooth-restoration complex may be reduced.

The aim of the present *in vitro* study was to investigate whether residual soft carious dentin beneath an adhesive occlusal composite restoration affects the fracture strength of restored teeth. We hypothesized that the presence of a soft, elastic layer of considerable size may contribute to increased failure of these restorations.

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Clinical Technique/Case Report

Stepwise Excavation in a Permanent Molar: 17-year Follow-up

FF Lima • RC Pascotto • AR Benetti

Clinical Relevance

Due to the risk of pulp exposure in deep carious lesions, stepwise excavation can be a conservative and successful option for selected cases, when signs and symptoms of a normal pulp are present.

SUMMARY

The current study presents a 17-year clinical report of stepwise excavation and indirect pulp capping in a lower right first molar, with great dentin destruction and a lack of dentin support of the cusps. At the first appointment, indirect pulp capping with calcium hydroxide and a temporary filling with zinc oxide cement were performed to minimize the risk of pulp exposure during excavation. After 45 days, the remaining carious tissue was removed and a restoration with glass-ionomer lining (Vitrebond) and resin composite (P-50) was performed. Satisfactory morphology and function of the restoration and pulp vitality were preserved for 17 years, thus indicating that stepwise excavation can be a good treatment alternative in selected cases.

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INTRODUCTION

An important concern in the treatment of deep caries lesions is the maintenance of pulp vitality.[1-2] Traditionally, restorative procedures involve the removal of soft demineralized dentin before the filling is placed. However, this approach may result in an invasion of bacteria if mechanical exposure of the pulp occurs. In order to minimize this problem, stepwise excavation and indirect pulp capping become an interesting possibility.

Stepwise excavation consists of removal of the infected dentin and preserving a layer of deeper caries-affected dentin, if pulp exposure is probable during excavation.[3-5] Thus, the first step consists of partial caries removal, indirect pulp capping with calcium hydroxide and cavity sealing. After an 8 to 12 week absence of signs and symptoms of pulp pathology,

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Restorative Thresholds for Carious Lesions: Systematic Review and Meta-analysis

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Abstract

Current evidence supports noninvasive/nonrestorative treatment of "early" carious lesions: those confined to enamel or reaching the enamel-dentin junction. The extent that dentists' thresholds for intervening restoratively have changed with this evidence is unknown. This systematic review aimed to determine dentists' and therapists' current lesion threshold for carrying our restorative interventions in adults/children and primary/permanent teeth. Embase, Medline via PubMed, and Web of Science were searched for observational studies, without language, time, or quality restrictions. Screening and data extraction were independent and in duplicate. Random-effects meta-analyses with subgroup and meta-regression analysis were performed. Thirty studies, mainly involving dentists, met the inclusion criteria. There was heterogeneity in sampling frames, methods, and scales used to investigate thresholds. The studies spanned 30 y (1983–2014), and sample representativeness and response bias issues were likely to have affected the results. Studies measured what dentists said they would do rather than actually did. Studies represented 17 countries, focusing mainly on adults (n = 17) and permanent teeth (n = 24). For proximal carious lesions confined to enamel (not reaching the enamel-dentin junction), 21% (95% confidence interval [CI], 15%–28%) of dentists/therapists would intervene invasively. The likelihood of a restorative intervention almost doubled (risk ratio, 1.98; 95% CI, 1.68–2.33) in high caries risk patients. For proximal lesions extending up to the enamel-dentin junction, 48% (95% CI, 40%–56%) of dentists/therapists would intervene restoratively. For occlusal lesions with enamel discoloration/cavitation but no clinical/radiographic dentin involvement, 12% (95% CI, 6%–22%) of dentists/therapists stated they would intervene, increasing to 74% (95% CI, 56%–86%) with dentin involvement. There was variance between countries but no significant temporal trend. A significant proportion of dentists/therapists said they would intervene invasively (restoratively) on carious lesions where evidence and clinical recommendations indicate less invasive therapies should be used. There is great need to understand decisions to intervene restoratively and to find implementation interventions that translate research evidence into clinical practice.

Keywords: caries, operative dentistry, restorative dentistry, minimally invasive dentistry, treatment planning, evidence based dentistry

Introduction

Previous understanding of dental caries as an infectious disease meant that lesion management was synonymous with carious tissue removal. However, contemporary understanding characterizes caries as a disease of imbalance in biofilm flora and activity, resulting in imbalance of de- and remineralization and does not support this aggressive symptomatic treatment. Increasing evidence endorses management by less invasive strategies to arrest lesions using biofilm removal, biofilm sealing-in strategies, and remineralization treatments (Marinho et al. 2003; Marinho et al. 2013; Ricketts et al. 2013; Schwendicke, Dörfer, et al. 2013; Schwendicke, Meyer-Lueckel, et al. 2013; Dorri et al. 2015; Innes et al. 2015).

Traditional approaches of removing tooth tissue affected by the caries process might have been justifiable when lesion progression from the outer aspect of enamel, through dentin, to the dental pulp, was thought to be relatively fast. In addition to the rate of caries progression being slower than was generally believed (Mejàre et al. 1999), wide availability of fluoride and intensive individual and public health efforts have promoted lesion arrest and slowed progression. The rates for carious lesions confined to enamel, transitioning to dentin lesions, have been estimated to be on the order of 21 lesions/100 tooth surface-years for permanent molars (i.e., only around 1 in 5 lesions can be expected to progress to reach dentin in a year) and 33 for primary molars (around 1 in 3 lesions progress to reach dentin within a year) (Mejàre et al. 1999; Mejare et al. 2001; Stenlund et al. 2002).

Given this limited risk of lesion progression and an increasing body of evidence supporting less interventive treatments, there is growing consensus that invasive (and largely restorative)

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A supplemental appendix to this article is available online.

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ORIGINAL ARTICLE

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Evaluation of mineral trioxide aggregate (MTA) *versus* calcium hydroxide cement (Dycal®) in the formation of a dentine bridge: a randomised controlled trial

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Aim: To assess the effectiveness of mineral trioxide aggregate (MTA) used as an indirect pulp-capping material in human molar and premolar teeth. **Methodology:** We conducted a clinical evaluation of 60 teeth, which underwent an indirect pulp-capping procedure with either MTA or calcium hydroxide cement (Dycal®). Calcium hydroxide was compared with MTA and the thickness of the newly formed dentine was measured at regular time intervals. The follow-up was at 3 and 6 months, and dentine formation was monitored by radiological measurements on digitised images using Mesurim Pro® software. **Results:** At 3 months, the clinical success rates of MTA and calcium hydroxide were 93% and 73%, respectively ($P = 0.02$). At 6 months, the success rate was 89.6% with MTA, and remained steady at 73% with calcium hydroxide ($P = 0.63$). The mean initial residual dentine thickness was 0.23 mm, and increased by 0.121 mm with MTA and by 0.136 mm with calcium hydroxide at 3 months. At 6 months, there was an increase of 0.235 mm with MTA and of 0.221 mm with calcium hydroxide. **Conclusions:** A higher success rate was observed in the MTA group relative to the Dycal® group after 3 months, which was statistically significant. After 6 months, no statistically significant difference was found in the dentine thickness between the two groups. Additional histological investigations are needed to support these findings.

Key words: *Calcium hydroxide, dentine bridge, mineral trioxide aggregate, pulp capping, randomised controlled trial*

INTRODUCTION

The consequences of pulp exposure from caries, trauma or unexpected tooth preparation procedures can be severe, with pain and infection. 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), is an attempt to maintain pulp vitality and avoid more extensive treatments[1].

There are key procedures in the management of vital teeth with deep carious lesions[2–4], which can be performed with high predictable long-term success rates[5].

Calcium hydroxide is the gold standard for pulp capping, following the initial publication by Zander[6] in 1939. It allows for the formation of a reparative dentine bridge through cellular differentiation, extracellular matrix secretion and subsequent mineralisation[7,8]. From a clinical point of view, it enables successful maintenance of pulp vitality[2], protects the pulp against thermoelectric stimuli and has an antimicrobial action. Calcium hydroxide is used as a reference for other capping agents, such as glass ionomer cement and adhesives[9–12].

However, in long-term clinical studies of pulp capping with calcium hydroxide-based materials, failure rates increase with the follow-up time[3]. Known disadvantages for this material include gradual degradation and tunnel defects in the newly formed dentine. In addition, an increased frequency of inflammatory cells and localised areas of pulp necrosis have been reported over time[13–16].

Mineral trioxide aggregate (MTA) is a pulp-sealing agent, essentially composed of a mixture of tricalcium silicate, dicalcium silicate, tricalcium aluminate, tetracalcium aluminoferrite and calcium sulphate dehydrate – which are the main components of Portland cement –

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ORIGINAL ARTICLE

Treatment outcomes of pulpotomy in permanent molars with irreversible pulpitis using biomaterials: A multi-center randomized controlled trial

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Abstract

Objective. To conduct a randomized clinical trial to compare the post-operative pain experience as well as clinical and radiographic outcomes of pulpotomy in human permanent molars with irreversible pulpitis using calcium enriched mixture (CEM) cement or mineral trioxide aggregate (MTA). ***Materials and mcethods.*** A total of 413 patients met the inclusion criteria and consented to participate. The patients were randomly allocated into two study arms: MTA pulpotomy (PMTA: $n = 208$) and CEM pulpotomy (PCEM: $n = 205$). Numerical rating scale questionnaires were utilized by the patients to record pain intensity (PI) over 7 days post-operatively. The patients were followed-up for 12 months to assess the clinical and radiographic outcomes of treatment. The data was analyzed using Chi-square, Cohen's kappa and *t*-tests. ***Results.*** There was no significant difference in the mean PI recorded during the 7 post-operative days between the two study arms ($p = 0.221$). The clinical and radiographic success rates for PMTA at 12-month follow-up were 98 and 95%, respectively; and 97 and 92% for PCEM, respectively. There was no significant differences in clinical ($p = 0.7$) and radiographic ($p = 0.4$) success rates between the two arms. ***Conclusions.*** Excellent treatment outcomes occurred in molar teeth with irreversible pulpitis undergoing pulpotomy with MTA and CEM biomaterials.

Key Words: *calcium enriched mixture, CEM, human, permanent tooth, pulpitis, pulpotomy*

Introduction

There is a range of treatment options for the management of pulpitis in teeth with extensive carious lesions. When a carious pulp exposure has occurred, the clinician may decide to cover the exposed pulp by direct pulp capping, remove the coronal part of the pulp (pulpotomy) or to carry out root canal treatment [1]. The ultimate treatment decision is affected by several variables including patient factors such as age and medical history and tooth factors such as whether it is a permanent or primary tooth, pulps were cariously exposed, contaminated by saliva, previously restored and/or periodontally involved [2].

Pulpotomy is well established and a common treatment modality for cariously exposed pulps in primary molars with well documented positive results [3]. This procedure can be defined as the surgical removal of the coronal portion of the pulp and the placement of a therapeutic agent to preserve the health of the remaining tissue [4].

In the permanent dentition, one of the most commonly adopted emergency treatment protocols for pain relief for irreversible pulpitis is complete or partial extirpation of the dental pulp [5]. The excellent prognosis of root canal treatment is well established (95% CI; 82.8 ± 1.19%) [6]; however, the procedure is complicated and time-consuming. Unfortunately, the only other feasible treatment option may be extraction due to financial restrictions in some areas of the world [7].

Recently, the use of conservative and simple pulpotomy techniques with one of the two biomaterials: (1) mineral trioxide aggregate (MTA) [8,9] and (2) calcium enriched mixture (CEM) cement [10-12] was suggested. Their rationale is based on the healing potential of the remaining radicular pulp of mature permanent molar teeth.

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MTA pulpotomy as an alternative to root canal treatment in children's permanent teeth in a dental public health setting

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ABSTRACT

Objective: This prospective clinical study evaluated the success of vital pulpotomy treatment for permanent teeth with closed apices using mineral trioxide aggregates (MTA) in a dental public health setting.

Methods: Twenty-seven mature permanent first molars and 2 premolars (in 25 patients) with carious exposure were treated using MTA pulpotomy. Age of patients ranged from 10- to 15-years (mean = 13.2 ± 1.74-years). Four trained and calibrated practitioners performed the same clinical procedure for all patients. Following isolation and caries removal, the inflamed pulp tissue was completely removed from the pulp chamber. This was followed by irrigation with 2% sodium hypochlorite. Haemostasis was achieved using a cotton pellet damped in normal saline. A white MTA paste was placed against the pulp orifices. MTA was covered with a damped cotton pellet and a base of IRM. Patients were recalled after 1 day where a glass ionomer liner and a final restoration were placed. Teeth were evaluated clinically and radiographically for up to 47 months.

Results: Mean follow-up period for all teeth was 25 ± 14 months. Twenty-six of the 29 teeth were clinically asymptomatic with no evidence of periradicular or root pathology during the follow-up period. The estimated success rate was 90%. Three teeth presented with clinical symptoms of pain and radiographic evidence of periradicular pathology that indicated root canal treatment (RCT) or extraction.

Conclusion: When managing carious pulp exposures of permanent teeth with closed root apices in children, MTA pulpotomy showed a high success rate.

Clinical significance: MTA pulpotomy for permanent molars in children is a viable alternative to RCT.

1. Introduction

The dental pulp is an integral element of tooth structure. A vital pulp tissue is responsible for supporting the tooth structure through reparative dentine production. Preserving pulp vitality is essential in maintaining vascularization and nutrition to the tooth that eventually will support tooth structure and reduce teeth mortality.

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MTA versus Biodentine: Review of Literature with a Comparative Analysis

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ABSTRACT

An ideal dental repair material should possess certain exclusive properties such as adequate adhesive ability, insolubility, dimensional stability, biocompatibility, bioactivity etc. New materials claiming better performance are continuously being introduced in the market to optimize the care of dental patients. Biodentine has been recently introduced as the "the first all-in-one, bioactive and biocompatible material for damaged dentin replacement". Manufacturers claim that Biodentine has noticeably shorter setting time in contrast to other silicate cements such as Mineral Trioxide Aggregate (MTA) and also has better mechanical and handling properties. This article is aimed to compare the properties of MTA and Biodentine analyzing the research work done in this field so far by various researchers all across the globe.

Keywords: Adhesive ability, Biological properties, Mechanical properties

INTRODUCTION

During the last 200 years, there have been many changes in the way of performing endodontic treatment. The standard protocol has undergone several modifications, more so because of increased demand from the patients for saving their teeth and advances in material science and innovative equipments. Bioceramics materials in endodontics can be considered as a magnanimous entity which has changed the prognosis of many cases which were once considered as next to impossible.

A remarkable biocompatible material, MTA with exciting clinical applications was pioneered by Dr. Mahmoud Torabinejad and co-workers in Loma Linda University [1]. MTA can be used in surgical and non–surgical applications, including direct pulp capping [2], temporary filling material, Perforation repairs in roots or furcations [3], apexification and root end fillings [4,5]. Despite the high clinical efficacy of this wonder cement, there were always some issues which prevented the clinicians to use it for many cases. The major ones being very long setting time and difficult manipulation.

Biodentin new bioactive calcium silicate-based cement has been recently launched in the dental market as a 'dentin substitute'. This new biologically active material aids its penetration through opened dentinal tubules to crystallize interlocking with dentin and provide mechanical properties. Biodentin has been formulated using MTA-based cement technology and hence; claims improvements of some of the properties such as physical qualities and handling, including its other wide range of applications like endodontic repair and pulp capping in restorative dentistry [6].

This review article attempts to compile and compare the properties of MTA and Biodentin for better clinical understanding.

Chemical Composition

Chemical composition of Biodentine: Biodentine is available in the form of a capsule containing the ideal ratio of its powder and liquid. The composition of powder is given in [Table/Fig-1] while the liquid contains calcium chloride which act as an accelerator, hydrosoluble polymer function as water reducing agent and water. However, the exact concentration of its components has not been provided by the manufacturer, various researchers have studied the same and provided the data. One such study performed by Camilleri J et al., has revealed the concentration of components of Biodentine [Table/Fig-1] [7].

Chemical composition of MTA: MTA is basically a mechanical mixture of three powder ingredients: portland cement (75%), bismuth oxide (20%) and gypsum (5%) [8]. According to MTA patent, it consist of calcium oxide (50-75 wt %) and silicon oxide (15-20 wt %), which together constitute 70-95% of the cement. Upon blending of these raw materials; tricalcium silicate, dicalcium silicate, tricalcium aluminate, tetracalcium aluminoferrite are produced [9]. There are two commercial types of MTA: grey and white and the difference lies due to the presence of iron in the former which further forms the tetracalciumalumino-ferrite phase. On the contrary, there is absence of oxide of iron in white MTA and hence the phase [Table/Fig-2] [10].

Setting Reaction

Setting reaction of Biodentine: The reaction of the powder with the liquid leads to the setting and hardening of the cement. Just after mixing, the calcium silicate particles of Biodentine react with water to from a high pH solution containing Ca^{2+}, OH^- and silicate ions. The hydration of the tricalcium silicate leads to the formation of a hydrated calcium silicate gel on the cement particles and calcium hydroxide nucleates. With the passage of time, calcium silicate hydrated gel polymerizes to form a solid network and the alkalinity of the surrounding medium increases due to the release of calcium hydroxide ions. Further the hydrated calcium silicate gel surrounds the unreacted tricalcium silicate particles and due to its relatively impermeable nature to water, it helps in slow down the effects of further reactions [11,12]. The complete reaction can be summarized as [6]:

$$2(3CaO.SiO_2) + 6H_2O \rightarrow 3CaO.2SiO_2.3H_2O + 3Ca(OH)_2$$

C_3S CSH

Setting reaction of MTA: The hydration reaction during setting occurs between tricalcium silicate and dicalcium silicate to form a calcium hydroxide and calcium silicate hydrate gel, producing an alkaline pH. A further reaction between tricalcium aluminate and calcium phosphate forms a high-sulphate calcium sulphoaluminate. The calcium ions leach through the dentinal tubules, and the concentration increases with time as the material cures [8,13,14].

Setting Time

The working time of Biodentine and MTA is given in [Table/Fig-3] [6]. The presence of setting accelerator in Biodentine results in faster

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Article type : Original Scientific Article

Outcome of full pulpotomy using Biodentine in adult patients with symptoms indicative of irreversible pulpitis

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Running title: Pulpotomy of carious exposures

Key words: Biodentine, deep caries, full pulpotomy, pulpitis.

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Abstract

Aim To assess the outcome of full pulpotomy using Biodentine in permanent teeth with carious exposures and symptoms indicative of irreversible pulpitis.

Methodology Sixty-four permanent molar teeth with symptomatic vital pulps in 52 patients aged 19-69 years were included. Preoperative pulpal and periapical diagnosis was established. After informed consent the tooth was anaesthetized, isolated using rubber dam and disinfected with 5% NaOCl before

Review Article

Vital pulp therapy using calcium-enriched mixture: An evidence-based review

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Abstract

Worldwide, casecontrol studies have revealed that the treatment outcomes of root canal therapy (RCT) are generally favorable; however, the overall epidemiological success rate of RCT in the general population is relatively low. On the other hand, vitality of dental pulp is a key factor in the long-term prognosis of permanent teeth; in recent years, vital pulp therapy (VPT) has received significant consideration as it has been revealed that the inflamed pulp has the potential to heal. In this review article, the current best evidence with regard to VPT using calcium-enriched mixture (CEM) cement in human permanent/primary teeth is discussed. A strategy based on a search using keywords for CEM cement as well as VPT was applied.

Keywords: Calcium-enriched mixture; CEM cement; endodontic; pulp cap; pulpitis; pulpotomy; vital pulp therapy

INTRODUCTION

Dental caries is still one of the most challenging infectious diseases worldwide; it affects oral/general health as well as the quality of life. Toothache and infection as the main sequelae of untreated caries/irreversible pulpitis are the main reasons for performing root canal therapy (RCT).[1] Permanent mature teeth with irreversible pulpitis/carious pulp exposure with/without clinical/radiological findings of apical periodontitis should be treated by RCT;[2] management of such teeth is the most common treatment carried out by dentists.

RCT has been shown to have a good success rate when carried out correctly.[3] Casecontrol studies have indicated that the pooled proportion of teeth surviving over 2–10 years following RCT ranged between 86–93%.[4] However, such studies are mainly carried out under controlled conditions; therefore, it is not valid to generalize such results. Moreover, the survival rate of endodontically treated teeth in comparison to vital teeth, especially molars, is very low.[5]

Results of epidemiological studies, which comprise < 1% of endodontic literature, are necessary for the evaluation of treatment outcomes of RCT in the general public.[6] Review of these studies indicates different success rates of RCT in various countries, ranging from 35% (Spain)[7] to 70–80% (Sweden, Portugal),[8,9] although the majority of developing/developed countries (i.e., Iran, Brazil, Turkey, Denmark, Scotland, and Canada) have reported success rates of around 50%.[10-15] As an imaginary scenario, by assuming that one root-treated tooth exists in the mouth of every adult in a country with an adult population of 100 million, it is estimated that on an average, ≈100 million endodontically treated teeth are present, of which ≈50 million require nonsurgical endodontic retreatment (NSER). Results of a systematic review have revealed that the pooled estimated success rate of NSER, if carried out by endodontists/experienced clinicians, is 77%.[16] Assuming that in an optimal scenario, this country has 2,000 endodontists, all of whom carried out the necessary NSER treatment on the failed 50 million teeth, the problem would still remain in ≈11.5 million teeth. The next option for these teeth is surgical endodontic retreatment (SER), which has a success rate of ≈60%.[17] As a result, the final treatment option of teeth with failed SER (≈4.5 million) is extraction. This imaginary scenario is representative of the inefficiency of (non)surgical endodontic (re)treatments worldwide, which may be related to inefficient clinical skills as well as the complex nature of RCT.

Serious multidimensional (inter)national effort is necessary for the improvement of the quality of RCT to increase success rates;[7,10-15] therefore, suggestions of treatment

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Treatment Outcomes of Full Pulpotomy as an Alternative to Tooth Extraction in Molars with Hyperplastic/Irreversible Pulpitis: A Case Report

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ABSTRACT

Root canal therapy (RCT) is a common and successful treatment for irreversible pulpitis due to carious pulp exposure in mature permanent teeth. However, it is often an expensive procedure, may require multiple appointments, and requires a high level of training and clinical skill, specifically in molars. Uninsured patients, low-income patients, and patients with limited access to specialist care often elect for extraction of restorable teeth with irreversible pulpitis. There is a need for an alternative affordable treatment option to preserve their teeth and maintain chewing function. A case of pulpotomy using calcium-enriched mixture (CEM) cement in two maxillary molars (#14 and 15) in a healthy 36-year-old patient is presented. Both teeth were diagnosed with symptomatic hyperplastic/irreversible pulpitis. Patient did not have dental insurance, was unable to afford RCT, and refused to extract the teeth. CEM pulpotomy and amalgam build-ups were done as an alternative to extraction. At 2-year recall, both teeth were functional with no signs/symptoms of inflammation/infection. Periapical radiographs and 3D images showed normal PDL around all roots. Pulpotomy with CEM biomaterial might be a viable alternative to tooth extraction for mature permanent teeth with hyperplastic/irreversible pulpitis, and can result in long-term tooth retention and improved oral health.

Keywords: Calcium-Enriched Mixture; Hyperplastic Pulpitis; Irreversible Pulpitis; Mineral Trioxide Aggregate; Permanent Teeth; Pulp Polyp; Pulpotomy; Vital Pulp Therapy

Introduction

Root canal therapy (RCT) is the universal treatment for mature permanent teeth with carious pulp exposure and irreversible pulpitis. The outcome of RCT in vital/nonvital teeth has been extensively studied [1]; it is a successful procedure with favorable prognosis [2]. However, this treatment is an expensive procedure, can require multiple appointments, and also requires a high level of training and clinical skill, specifically in molar teeth [3]. Therefore, for uninsured patients, low-income patients, and patients with limited access to specialist care, sometimes the treatment of choice for a molar with irreversible pulpitis is tooth extraction.

An alternative option for these patients who desire to save their teeth is a vital pulp therapy (VPT) procedure [4]. Vital pulp therapy is the treatment of choice following carious pulp exposure in immature teeth [5]; it has a favorable outcome due to adequate pulpal blood supply and the healing potential of pulp tissue [6]. However, studies on long-term outcome of VPT in mature teeth with irreversible pulpitis are limited [7], which makes it challenging to present it as a predictable treatment option to patients.

The outcome of VPT depends on the type of material used to cover the remaining coronal/radicular pulp. Calcium-silicate based cements are the materials of choice. These materials are biocompatible and bioactive. They produce hydroxyl apatite

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REVIEW ARTICLE

Regenerating the Pulp–Dentine Complex Using Autologous Platelet Concentrates: A Critical Appraisal of the Current Histological Evidence

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BACKGROUND: Autologous platelet concentrates such as platelet-rich plasma (PRP) and platelet-rich fibrin (PRF) have gained overwhelming popularity in regenerative endodontics. Clinical evidence reveals the lack of a particular advantage of using PRP or PRF over an evoked blood clot in promoting canal wall thickening and/or continued root development in immature necrotic teeth. Moreover, despite stimulating tissue repair and repopulating the root canals of immature and mature permanent teeth, the new vital tissue may not possess the functional activity of the native pulp tissue.
METHODS: To better understand the origin, nature, and long-term fate of the tissue types found within the pulp space, we critically examine all available histo-/morphological evidence for pulp–dentine complex regeneration using PRP and/or PRF, alone or together with an evoked blood clot, specialised or unspecialised primary cells, and other biomaterials.
RESULTS: Histological data from clinical studies is scant. Reportedly, the inner dentinal surface supports cementum-like tissue formation, but this interface likely deviates in structure and function from the native cementodentinal junction. Presence of bone-like tissue within the pulp space is intriguing since de novo osteogenesis requires closely coordinated recruitment and differentiation of osteoprogenitor cells. Compared to untreated necrotic teeth, an evoked blood clot (with/without PRF) improves fracture resistance. Tooth regeneration using PRF and dental bud cells is unreliable and the constituent neoformed tissues are poorly organised.
CONCLUSION: PRP/PRF fail to demonstrate a significant advantage over an induced blood clot, alone. The true nature of neoformed tissues remains poorly characterised while their response to subsequent insult/injury is unexplored.

Keywords Autologous platelet concentrate · Platelet-rich plasma · Platelet-rich fibrin · Regenerative endodontics

1 Introduction

Regenerative endodontics has evolved over the years as a treatment option for not only immature permanent teeth with open apices (i.e., incomplete root development) but also for apical periodontitis in mature permanent teeth [1–3]. Based on the triad of adult stem/progenitor cells, morphogens, and a suitable scaffold, the focus of regenerative endodontics is to reconstitute the lost tooth tissue, i.e., the pulp–dentine complex [4]. Clinically and experimentally, one of the most frequently used technique comprises of intentionally provoked periapical bleeding in order to induce a blood clot within the disinfected canal. Rich in stem cells, inflammatory cells, fibroblasts, and growth factors that are essential to wound healing [5], evidence indicates that a blood clot act as a reliable tissue engineering scaffold in regenerative endodontics [6]. Since platelets are key players in wound healing pathways and release substances such as vascular endothelial growth factor (VEGF) and transforming growth factor beta (TGF-

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Review Article

Current and future options for dental pulp therapy☆

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SUMMARY

Dental pulp is a connective tissue and has functions that include initiative, formative, protective, nutritive, and reparative activities. However, it has relatively low compliance, because it is enclosed in hard tissue. Its low compliance against damage, such as dental caries, results in the frequent removal of dental pulp during endodontic therapy. Loss of dental pulp frequently leads to fragility of the tooth, and eventually, a deterioration in the patient's quality of life. With the development of biomaterials such as bioceramics and advances in pulp biology such as the identification of dental pulp stem cells, novel ideas for the preservation of dental pulp, the regenerative therapy of dental pulp, and new biomaterials for direct pulp capping have now been proposed. Therapies for dental pulp are classified into three categories; direct pulp capping, vital pulp amputation, and treatment for non-vital teeth. In this review, we discuss current and future treatment options in these therapies.

1. Introduction

Dental pulp, surrounded by dentin, supports tooth vitality through the supply of essential factors via apical foramen and plays a key role in tooth maintenance [1]. Through the apical foramen, blood vessels supply nutrients and remove waste products, and the neural network indicates the presence of harmful stimuli through pain [2]. Various immune cells in the pulp including dendritic cells, macrophages, and T-lymphocytes prevent the invasion of microorganisms and other foreign antigens [2]. When sound dentin has been lost due to tooth wear, fracture, or caries, odontoblasts or odontoblast-like cells repair the tooth by depositing tertiary dentin, which is reactionary and reparative dentin, on the pulp chamber surface [2].

After the progression of dental caries and/or tooth fractures in a tooth crown, a bacterial infection and subsequent inflammatory response of dental pulp occurs, and the internal pressure in the pulp chamber significantly increases, resulting in pulp tissue ischemia with severe pain [2]. To release patients from the pain and eliminate infection of dental pulp, dentists eventually remove dental pulp by pulpectomy [3]. If pulpectomy is not performed, ischemia develops through impaired blood circulation, followed by pulp necrosis and periapical disease [4].

Resistance to external stimuli decreases in non-vital teeth due to complete loss of perception and immune functions, and the teeth become fragile due to loss of metabolic capacity [3]. Additionally, a non-vital tooth is immunocompromised and often re-infected by bacteria. Loss of sensation when the re-infection occurs can enable the progression of dental caries. The success rate of root canal retreatment is not high [5–8], and it is often necessary to repeat root canal treatment. Repetition of root canal treatment makes teeth more fragile and leads to cracking and/or fracture of the roots. As a result, the tooth has to be extracted, leading to a deterioration in the quality of life.

It is believed that a lot of root canal treatments and tooth extractions could be avoided if the proper direct pulp capping is carried out or pulp regeneration therapy is developed. This review will focus on potential approach for dental pulp preservation and regeneration therapies.

2. Current trends and perspectives of direct pulp capping

Untreated exposure of pulp to the oral cavity is the cause of pulpitis and pulp necrosis [9]; direct pulp capping or pulpotomy are clinically carried out in order to avoid pulp death. Direct pulp capping with dental materials is used to treat exposed vital pulp to facilitate the formation of reparative dentin. Generally, the most

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Assessment of alternative emergency treatments for symptomatic irreversible pulpitis: a randomized clinical trial

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Running title: Emergency management of irreversible pulpitis

Key words: emergency treatment, endodontics, irreversible pulpitis, pain, pulpotomy, treatment modalities

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ORIGINAL ARTICLE

A follow-up study of pulpotomies and root canal treatments performed under general anaesthesia

Pierre-Yves Cousson · Emmanuel Nicolas · Martine Hennequin

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Abstract
Objectives A previous study considered whether the proportions of clinically satisfactory root canal treatments (RCT) done under general anaesthesia (GA) or under local anaesthesia were equivalent, but the proportion of treatment with long-term satisfactory endodontic outcomes remains unknown. Moreover, no evaluation of pulpotomies performed under GA has been reported.
Materials and methods From 614 endodontic treatments (ETs) performed on permanent teeth under GA, 225 [193 RCT and 32 pulpotomies (P)] were examined after follow-up periods of 1–6 months (71 cases), 6–24 months (77 cases) and over 2 years (77 cases). Changes in the periapical index between the treatment date (T0) and the control time (T1) allowed the treatment to be classified as "success," "uncertain outcome" or "failure." Explicative variables for success of ET were the duration of follow-up and tooth-related criteria expected to affect the outcomes of endodontic treatment.
Results Overall, 87 % of ETs were scored as "success," while 9 % were uncertain and 4 % were failures. There was no difference in the distribution of success in relation with the type of tooth, the pulpal status, the level of endodontic difficulty, the periapical status or the technical quality of RCT. The proportion of endodontic cases with high level of difficulties was higher in the P group than in the RCT group.
Conclusion Longer follow-ups and higher numbers of cases are needed to analyse the factors affecting success and failure in endodontic treatments performed under GA.
Clinical relevance The relatively high rates of success of pulpotomies and RCT support undertaking endodontic treatment under GA.

Keywords Endodontics · Follow-up · General anaesthesia · Pulpotomy · Root canal treatment

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Introduction

It is commonly accepted that endodontic procedures can be complex and difficult to undertake under general anaesthesia (GA). Limited mouth opening, tongue protrusion due to intubation, the short duration of the session, uncertain diagnosis due to the inability of patients to describe symptoms and the need to complete a maximum amount of treatment at each session are all problems that are greater when working under GA. A previous study [1] considered whether the proportions of clinically satisfactory root canal treatments done under GA or under local anaesthesia in a general practice setting were equivalent. It reported that 63 % of root canal treatments were technically satisfactory in both groups and that this rate was significantly lower for molars than for other teeth. The study supported the feasibility of root canal treatment (RCT) in patients treated under GA, but the proportion of treatment that achieves satisfactory endodontic treatment (ET) outcomes remains unknown. Moreover, pulpotomies are sometimes indicated in vital permanent teeth treated under GA in order to reduce the duration of the intervention but currently no evaluation for such treatments has been reported.

A variety of other parameters, such as restorative factors and the biological variables related to individuals with special

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ORIGINAL ARTICLE

Five-year results of vital pulp therapy in permanent molars with irreversible pulpitis: a non-inferiority multicenter randomized clinical trial

Saeed Asgary · Mohammad Jafar Eghbal · Mahta Fazlyab · Alireza Akbarzadeh Baghban · Jamileh Ghoddusi

Received: 18 January 2014 / Accepted: 9 April 2014

Abstract
Objectives Previous reported results of up to 12 months as well as 24-month follow-ups revealed superior and equivalent treatment outcomes for vital pulp therapy (VPT) using calcium-enriched mixture cement (CEM) in comparison with root canal therapy (RCT) for mature molars with established irreversible pulpitis, respectively. Present non-inferiority multicenter randomized clinical trial assesses the final long-term (5-year) results as well as the effects of patients' age/gender and the presence of preoperative periapical lesion on the treatment outcomes.
Materials and methods A total number of 407 patients were blindly allocated into two treatment groups [group 1 (VPT/CEM, n=205) and group 2 (RCT, n=202)] treated in 23 health-care centers by calibrated dentists. The treatment outcomes were assessed after 60 months.
Results The 5-year results revealed no significant differences in the successes of both study arms (P=0.29); a total number of 271 patients were available (~33 % were lost to follow-up). The patients' age/gender did not affect the outcomes; the presence of preoperative periapical lesion also did not implement a significant effect in both groups (P>0.05).
Conclusions As an alternative for RCT, VPT/CEM can be considered as a valid treatment for vital mature permanent molars clinically diagnosed with irreversible pulpitis.
Clinical relevance Considering the favorable outcomes of 6- to 60-month follow-ups, as an evidence-based/simple/affordable/effective/biologic approach in cases of irreversible pulpitis, VPT/CEM is highly recommended for universal clinical practice.

Keywords Calcium-enriched mixture · CEM cement · Human · Molar · Pulpitis · Pulpotomy · Randomized clinical trial · Randomized controlled trial · Treatment outcome · Vital pulp therapy

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Introduction

The dental pulp can be exposed by accidental trauma or during preparation of a tooth for restoration which can be diagnosed as mechanical or carious exposure [1]. Moreover, each day, there are innumerable patients seeking for a dental visit to get rid of toothache steaming from symptomatic vital pulps [2]. In mature teeth, the treatments for inflamed exposed pulps include maintaining the tooth via root canal therapy (RCT) or tooth extraction; when compared to the first option, the later represents the non-optimal choice [3, 4]. The rationale for the RCT is based on the following: (i) the unreliability of vital pulp therapy (VPT) on these teeth, which is currently proved to be wrong by a high level of evidence (LoE) trials [5, 6], and

Comparative Evaluation of Postoperative Pain and Success Rate after Pulpotomy and Root Canal Treatment in Cariously Exposed Mature Permanent Molars: A Randomized Controlled Trial

Mohit Galani, MDS, Sanjay Tewari, MDS, Pankaj Sangwan, MDS, Shweta Mittal, MDS, Vinay Kumar, MDS, and Jigyasa Duhan, MDS

Abstract

Introduction: The aim of this study was to compare postoperative pain and success rate following pulpotomy and root canal treatment. **Methodology:** Fifty-four permanent teeth with carious exposures were randomly divided equally into 2 groups. Mineral trioxide aggregate pulpotomy was performed in the experimental group and root canal treatment was performed in the control group, using standardized protocols. The treated teeth were restored with base of glass-ionomer cement followed by composite restoration. Pain was recorded every 24 hours for 7 days after intervention. Clinical and radiographic evaluations were done every 3 months for 18 months. The data collected were statistically analyzed. **Results:** At the end of follow-up, overall success rate was 85% in the pulpotomy group and 87.5% in the root canal treatment group ($P > .05$). Significant difference in pain incidence and pain reduction was found between the 2 groups ($P < .05$), with lower scores reported in the pulpotomy group. **Conclusion:** Pulpotomy can be an alternative treatment for management of symptomatic permanent teeth with deep caries lesions. *(J Endod 2017;■:1–10)*

Key Words

Mineral trioxide aggregate, periapical index, postoperative pain, pulpotomy, root canal treatment, success

Significance

Pulpotomy can be an alternative treatment for management of symptomatic permanent teeth in adults with deep caries lesions.

Inflamed pulp as a result of deep caries can be treated clinically by either preserving the tissue or excising it completely, followed by obturation of the tooth (1). However, the best modality of treatment still remains a controversial issue (2, 3). The preferred treatment for symptomatic or asymptomatic teeth with deep caries lesion reaching the pulp is root canal treatment (RCT) (2, 4). It has certain disadvantages, being time-consuming (5), expensive (5), and requiring multiple visits (6) making the teeth susceptible to fractures due to loss of tooth structure (7). Epidemiologic surveys have shown failure rates ranging from 24% to 66% as a result of inadequate RCTs performed mainly by general dentists (5). A recent systemic review by Ng et al (8) proclaimed that success rate of RCT had not improved over past few decades and molars had poor survival rates (odds ratio = 1.26) compared with nonmolar teeth (9). Preserving the vital pulp helps in retaining proprioceptive, reparative, tooth sensitivity (innervation), vascularization, and damping functions provided by vital pulp, which help in protecting against harmful stimuli (2).

Vital pulp therapy is usually performed in young patients with traumatic, carious, or mechanical exposure of pulp with no signs of periapical pathology (2, 10). Pulp amputation or pulpotomy is defined as a procedure in which a part of an exposed vital pulp is removed, usually as a means of preserving the vitality and function of the remaining part (7). Coronal pulpotomy has been considered as a definitive treatment to manage carious pulp exposures for primary teeth and young immature permanent teeth, as well as in treating traumatic pulp exposures in mature teeth with signs of reversible pulpitis. In adults, it may be undertaken for emergency management of tooth pain before RCT (11, 12). It has been proposed that age might be a limiting factor in determining success of vital pulp therapy in permanent teeth with carious exposures (10). However recent studies (5, 6, 13–15) have observed success rates ranging from 82% to 95% using modern restorative materials in mature permanent teeth, thereby suggesting that pulpotomy can be a useful alternative to RCT in adults.

The mean quality scores (16, 17) for the studies relating to pulpotomy have been found to range between 7 and 10 and most of them are either retrospective (18), case series (14, 19), or case reports (15, 20). Further, only 1 randomized controlled trial

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Radiological and clinical assessment of pulpotomy on mature permanent molars with irreversible pulpitis: literature review

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Abstract

Introduction: Endodontic treatment has long been considered the only conservative therapeutic option for teeth with irreversible acute pulpitis. Histological studies have shown that the inflammation is confined to a limited surface of the pulp, near the decaying lesion, and it is not uncommon to find normal histology in the coronary pulp away from decayed surfaces as well as in roots. In dentistry, it is universally accepted that the vital pulp tissue should be preserved if possible.

Aim: The objective of this study is to review the literature on the clinical and radiographic assessment criteria for coronary pulpotomy therapeutics on mature permanent teeth with irreversible acute pulpitis.

Materials and Methods: To find relevant articles on this therapy, an electronic search strategy on PubMed, Cochran Library and Science Direct databases using the combination pulpotomy and pulpitis and permanent tooth, for indexed studies from January 2008 to April 2018.

Results: Results of this study indicated favorable success rates for this therapy. A 2018 study reported 98.4% of clinical and radiographic successes at six months. At one year, it reported 100% clinical success and 98.4% radiographic success with the use of Biodentine. Furthermore, it reported 100% clinical success and 97.5% of radiographic success rate with the use of mineral trioxide aggregate (MTA) in the first year, and 92.7% of radiograph success after three years. In 2014, a publication reported 98.19% clinical success rate with cement-enriched mixture (CEM) over a 27 month period. However, the X-ray success rates were 86.7%.

Conclusion: This treatment can be a realistic alternative for mature permanent human molars with irreversible pulpitis symptoms. But other large-scale multicentered clinical trials are strongly encouraged to substantiate this hypothesis.

Keywords: Irreversible pulpitis, Full pulpotomy, Mature permanent teeth, Permanent teeth, Pulpitis, Pulpotomy.

Introduction

Irreversible pulpitis is an inflammatory condition of the dental pulp, associated with clinical and histological signs.[1] Indeed, irreversible pulpitis are often associated with a spontaneous or lingering pain after a specific triggering, they can, sometimes, occur without symptoms.[1] In other words, correlation of clinical signs and symptoms and the pulp histopathological state is not always accurate.

Histological studies showed that the inflammation is confined to a limited area of the pulp, near the carious lesion and it is not uncommon to find a normal histology in the coronal pulp far away from carious sites and in the roots pulp as well.[2]

Endodontic treatment was considered the only conservative therapeutic option for teeth with irreversible pulpitis. However, the high frequency of inadequate canal obturations linked to apical periodontitis, despite new preparation and canal obturation technologies, increases the option to preserve the pulp vitality in current therapies.[3] Indeed, improved understanding of the pulp biology and potential regenerative and healing of inflamed pulp has encouraged this therapeutic option in cases of irreversible pulpitis.

Considering the pulpo dentin complex healing potential when it is no longer irritating a high rate of successful treatment can be achieved. However, on teeth with irreversible pulpitis clinical signs and indicative symptoms, the inflamed part of the dental pulp must be removed by partial or full pulpotomy for the remaining pulp tissue to heal.[4] This turns out to be a success when using bioactive endodontic cement, such as mineral trioxide aggregate (MTA), cement-enriched mixture (CEM), Biodentine... Thus, according to Glickman, full pulpotomy provides a greater chance to remove the irreversibly inflamed and infected pulp tissue.[5] It consists of eliminating the whole pulp coronal up to canal orifices.

Several recent studies among young people and adults[6,7] have shown very high success rates. Thus the objective of this study was to review the current endodontic literature so as to assess clinical and radiological criteria of pulpotomy therapy on mature permanent molars with irreversible acute pulpitis.

Materials and Methods

Search strategy: To find relevant articles on irreversible pulpitis care by pulpotomy, an electronic search strategy through databases of PubMed/MedLine via Hinari, Cochrane Library and Science Direct was

Direct Pulp Capping after a Carious Exposure Versus Root Canal Treatment: A Cost-effectiveness Analysis

Falk Schwendicke, DMD, and Michael Stolpe, PhD†*

Abstract

Introduction: Excavation of deep caries often leads to pulpal exposure even in teeth with sensible, nonsymptomatic pulps. Although direct pulp capping (DPC) aims to maintain pulpal health, it frequently requires follow-up treatments like root canal treatment (RCT), which could have been performed immediately after the exposure, with possibly improved outcomes. We quantified and compared the long-term cost-effectiveness of both strategies. **Methods:** A Markov model was constructed following a molar with an occlusally located exposure of a sensible, nonsymptomatic pulp in a 20-year-old male patient over his lifetime. Transition probabilities or hazard functions were estimated based on systematically and nonsystematically assessed literature. Costs were estimated based on German health care, and cost-effectiveness was analyzed using Monte Carlo microsimulations. **Results:** Despite requiring follow-up treatments significantly earlier, teeth treated by DPC were retained for long periods of time (52 years) at significantly reduced lifetime costs (545 vs 701 Euro) compared with teeth treated by RCT. For teeth with proximal instead of occlusal exposures or teeth in patients >50 years of age, this cost-effectiveness ranking was reversed. Although sensitivity analyses found substantial uncertainty regarding the effectiveness of both strategies, DPC was usually found to be less costly than RCT. **Conclusions:** We found both DPC and RCT suitable to treat exposed vital, nonsymptomatic pulps. DPC was more cost-effective in younger patients and for occlusal exposure sites, whereas RCT was more effective in older patients or teeth with proximal exposures. These findings might change depending on the health care system and underlying literature-based probabilities. *(J Endod 2014;■:1–7)*

Key Words

Caries, dental, endodontics, health economics, public health, pulpal vitality

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The removal of deep caries lesions is often associated with risks for the integrity and vitality of the pulp (1), and although more selective excavation methods (ie, incomplete or stepwise excavation) might reduce the risk of pulpal exposure compared with conventional excavation attempting complete removal of carious dentin, such techniques are not yet widely adopted (2–4). Considering the high prevalence of deep caries lesions (5), the treatment of exposed pulps can be assumed to be daily routine for most practitioners. Thus, in case of exposure of a sensible and nonsymptomatic (ie, presumably healthy) pulp, dentists are faced with the decision to either perform direct pulp capping (DPC) or, anticipating the capped pulp to require follow-up treatments, to immediately initiate root-canal treatment (RCT).

Although teeth with DPC after pulpal exposure during caries removal often require follow-up treatments (6), RCT was shown to provide predictable outcomes (7, 8), with root canal–treated teeth seldom requiring further treatments (9). Nevertheless, dentists often perform DPC (3), attempting to maintain pulpal health and accepting the possible need for follow-up treatments. Such treatments usually involve RCT but possibly under changed clinical conditions compared with the initial treatment option. Directly capped pulps might cause pain, become necrotic, or become infected leading to the development of periapical lesions. These conditions have been found to reduce the probability of retaining the tooth after RCT in the long-term (8). Thus, there might be a conflict between attempting to maintain the presumed pulpal health, thereby postponing or obviating more invasive treatments, and predictably avoiding pain or early follow-up treatments. In addition, the costs associated with both therapies remain unknown, with DPC presumably being less costly initially, whereas RCT might avert follow-up treatments and thus reduce long-term costs.

The present study aimed to assess the cost-effectiveness of both direct capping and RCT for pulps being exposed during caries removal. Cost-effectiveness was evaluated for different subgroups and clinical situations, and the robustness of our findings was determined.

Materials and Methods

Model

We simulated the treatment of a deeply carious molar with a sensible, nonsymptomatic (ie, painless) pulp being exposed during caries removal. Note that we did not discriminate "carious" exposure (ie, in carious dentin) from "accidental" exposure (ie, in sound dentin) (10) because these were not reported separately in most studies. However, we did assess the uncertainty resulting from this nondiscrimination (see later). Pulp exposures with no association to caries lesions (ie, traumatic exposures) were not included. We compared DPC (ie, capping of the exposed pulp) using a medication (calcium hydroxide or, in sensitivity analyses, mineral trioxide aggregate [MTA]) and subsequent direct restoration with RCT (ie, vital pulpectomy) followed by a cast coronal restoration. The caries lesion was assumed to be extensive (ie, to involve both proximal and occlusal surfaces). All analyses were performed in the context of German health care.

A Markov model was constructed for both interventions (TreeAge Pro 2013; TreeAge Software, Williamstown, MA) consisting of initial and follow-up health states. The likelihood of teeth transitioning to the next health state was based on transition probabilities. Each transition was performed by traversing treatment states, thereby accruing costs. Simulation was performed in discrete 6-month cycles, with the sequence of events constructed according to current evidence and existing literature in the field (11).

RESEARCH REPORTS
Biomaterials & Bioengineering

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Dentin Caries Zones: Mineral, Structure, and Properties

ABSTRACT

Caries Detector staining reveals 4 zones in dentin containing caries lesions, but characteristics of each zone are not well-defined. We therefore investigated the physical and microstructural properties of carious dentin in the 4 different zones to determine important differences revealed by Caries Detector staining. Six arrested dentin caries lesions and 2 normal controls were Caries-Detector-stained, each zone (pink, light pink, transparent, apparently normal) being analyzed by atomic force microscopy (AFM) imaging for microstructure, by AFM nano-indentation for mechanical properties, and by transverse digital microradiography (TMR) for mineral content. Microstructure changes, and nanomechanical properties and mineral content significantly decreased across zones. Hydrated elastic modulus and mineral content from normal dentin to pink Caries-Detector-stained dentin ranged from 19.5 [10.6-25.3] GPa to 1.6 [0.0-5.0] GPa and from 42.9 [39.8-44.6] vol% to 12.4 [9.1-14.2] vol%, respectively. Even the most demineralized pink zone contained considerable residual mineral.

KEY WORDS: dentin, caries, mineral, mechanical properties, atomic force microscopy

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INTRODUCTION

Current management of caries involves non-invasive techniques and maximum conservation of tooth structure. Differentiation between heavily infected outer carious dentin and demineralized, affected inner dentin reduces the risk of pulp exposure, maximizing reparative potential (McComb, 2000). Different layers of dentin caries lesions have been classified by clinical and laboratory techniques (Fusayama and Terachima, 1972; Anderson *et al.*, 1985), but recommendations may conflict or overlap. Therefore, it is essential that the nature of and variations in such lesions be understood.

Caries-staining products have been developed (Fusayama and Terachima, 1972) to assist clinicians during caries removal. Although the biochemical principle of staining carious dentin has been reported (Ohgushi and Fusayama, 1975; Kuboki *et al.*, 1977; Kuboki *et al.*, 1983), it remains unclear what characteristics of the lesion are stained, or how staining is related to microstructural features of various caries lesion zones. Not all stainable dentin is infected (Kidd *et al.*, 1993), but the absence of stain does not ensure bacterial elimination (Anderson *et al.*, 1985).

Caries staining characteristics have been described as pink, light pink, transparent, and apparently normal dentin, and nano-indentation properties of moderately active and arrested caries lesions have been compared (Zheng *et al.*, 2003). Nanohardness values for intertubular dentin increased from the pink zone to the apparently normal dentin layer (outer to inner). In another study, mechanical properties across dentin caries lesions decreased as the lesion surface was approached (Angker *et al.*, 2004b).

Hydration and dehydration affect dentin mechanical properties, especially demineralized dentin (Kinney *et al.*, 1993, 1996; Marshall, 1993). Therefore, properties measured under hydrated conditions provide more realistic estimates of those found *in vivo* (Marshall *et al.*, 2001).

The hypothesis for this study was that Caries Detector staining allows for the discrimination of carious zones with distinct microstructural characteristics, mechanical properties, and mineral contents. We investigated the zones revealed by Caries Detector staining in arrested caries lesions. We related these zones to their microstructural features as determined by atomic force microscopy (AFM), nanomechanical properties as determined by AFM nano-indentation, and mineral concentration.

MATERIALS & METHODS

Tooth Selection and Sample Preparation

Teeth were collected following protocols approved by the UCSF Committee on Human Research, and informed consent was obtained for the use of human tissues. Eight freshly extracted, unrestored third molars (6 carious, 2 non-carious controls), obtained from research participants requiring extractions for dental treatment, were sterilized by gamma radiation (White *et al.*, 1994), then stored in Hanks' balanced salt solution at 4ºC (Habelitz *et al.*, 2002). After the tooth was longitudinally sectioned

The Caries Process and Its Effect on the Pulp: The Science Is Changing and So Is Our Understanding

Lars Bjørndal, DDS, PhD

Abstract

The understanding of the caries process and its effect on the pulp is presented in the context that caries does develop in various rates of progression. Early in the caries process, the pulp reflects changes within lesion activity. Thus, the early pulp response is reversible. Later, the rate of caries progression is reflected by the quality of the tertiary dentin. Slowly progressing lesions create tertiary dentin resembling normal tubular dentin. Rapidly progressing lesions lead to the production of atubular dentin or complete absence of tertiary dentin, as well as pulp necrosis and apical pathology. Finally, the nature of the untreated deep carious lesion is an ecosystem that might undergo significant changes. The untreated lesion is temporarily converted from an active and closed lesion environment into one that is open and slowly progressing. The analysis of untreated carious lesions has transformed the treatment philosophy of deep carious lesions. *(J Endod 2008;34:S2-S5)*

Key Words

Dental caries, dental pulp, dentin, indirect pulp treatment, stepwise excavation, tertiary dentin

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Can We Obtain Consensus on Caries Pathology?

Caries can be compared with a train that passes through many stations. Imagine that each station represents a specific stage of caries progression. The first station represents the initial surface etching at the outer enamel layer, leading to the dull white appearance of the active progressing enamel lesion. The last station represents the deepest layer of the carious tooth, with a necrotic, infected root canal system and the presence of apical pathosis. Investigators, clinicians, and researchers who enter the "caries train" have typically focused on only a few stations. They might also have different understandings and opinions about how to treat dental caries. Their opinions have developed from a mixture of clinical empirical tradition and an understanding from research. These opinions could be named the cariologist opinion, the operative opinion, and the endodontic opinion.

Some Opinions about the Approach to Dental Caries

The classic cariologist opinion is focused on the prevention of caries and further progression of the established lesion. The initial focus is on the white spot lesion, whose histologic picture is visualized in the laboratory via transmitted or polarized light. Treatment philosophies here are typically related to nonoperative and preventive approaches. If caries has progressed into the dentin, with demineralized dentin being visible on the x-ray or, at most, extending through half the thickness of the dentin, excavation procedures are planned to avoid pulp exposures.

The operative opinion is typically initiated when caries has progressed into a clinical breakdown of the enamel surface and with carious dentin exposure. Without focusing on specific details about caries pathology, the cavity needs to be "drilled and filled." A lesion means an exposure of the pulp, and this might be avoided by leaving carious dentin behind. The operative opinion also tends to be a two-edged sword, because sometimes the design of the cavity overrides the fact that the caries lesion might not be in need of operative intervention. However, for esthetic or other reasons, the operative intervention is carried out with a minimally invasive approach, even though the actual lesion is dark, discolored, arrested caries.

Finally, the endodontic opinion deals with the prevention of an infected pulp and subsequent apical pathosis; the issue of a lesion mainly concerns this region. Therefore, all carious dentin should be removed, even if the result is a pulp exposure. The existence of these virtual opinions was reflected in a recent practice-based research network to determine dentists' treatment methods for deep caries lesions in which one would expect pulpal exposure (1). The survey findings showed that 62% of the responding dentists would remove all caries (operative opinion), 18% would partially remove caries (cariologist opinion), and 21% would initiate endodontic treatment (endodontic opinion). Differences in decision making for treating deep carious lesions in primary molars have also recently been reported (2).

Actually, this topic is not new, as shown in the following quotations: "It is better that a layer of discolored dentin should be allowed to remain for the protection of the pulp rather than run the risk of sacrificing the tooth" (3). In contrast, Black (4) wrote: ". . . it will often be a question whether or not the pulp will be exposed when all decayed dentin overlaying it is removed . . . It is better to expose the pulp of a tooth than to leave it covered only with softened dentin."

It is necessary to remain within the historical perspective to understand how these different opinions have justified various treatment concepts. The endodontic opinion advocating an invasive pulp treatment in relation to caries might very well have gained

Vital Pulp Therapy in Vital Permanent Teeth with Cariously Exposed Pulp: A Systematic Review

Panuroot Aguilar, MSc, DDS, and Pairoj Linsuwanont, DDS, MDSc, PhD

Abstract

Introduction: This systematic review aims to illustrate the outcome of vital pulp therapy, namely direct pulp capping, partial pulpotomy, and full pulpotomy, in vital permanent teeth with cariously exposed pulp. **Methods:** Electronic database MEDLINE via Ovid, PubMed, and Cochrane databases were searched. Hand searching was performed through reference lists of endodontic textbooks, endodontic-related journals, and relevant articles from electronic searching. The random effect method of weighted pooled success rate of each treatment and the 95% confidence interval were calculated by the DerSimonian-Laird method. The weighted pooled success rate of each treatment was estimated in 4 groups: >6 months–1 year, >1–2 years, >2–3 years, and >3 years. All statistics were performed by STATA version 10. The indirect comparison of success rates for 4 follow-up periods and the indirect comparison of clinical factors influencing the success rate of each treatment were performed by *z* test for proportion ($P < .05$). **Results:** Overall, the success rate was in the range of 72.9%–99.4%. The fluctuation of the success rate of direct pulp capping was observed (>6 months–1 year, 87.5%; >1–2 years, 95.4%; >2–3 years, 87.7%; and >3 years, 72.9%). Partial pulpotomy and full pulpotomy sustained a high success rate up to more than 3 years (partial pulpotomy: >6 months–1 year, 97.6%; >1–2 years, 97.5%; >2–3 years, 97.6%; and >3 years, 99.4%; full pulpotomy: >6 months–1 year, 94%; >1–2 years, 94.9%; >2–3 years, 96.9%; and >3 years, 99.3%). **Conclusions:** Vital permanent teeth with cariously exposed pulp can be treated successfully with vital pulp therapy. Current best evidence provides inconclusive information regarding factors influencing treatment outcome, and this emphasizes the need for further observational studies of high quality. *(J Endod 2011;37:581–587)*

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Key Words

Dental caries, direct pulp capping, full pulpotomy, partial pulpotomy, systematic review, treatment outcome

Up until now, there has been no agreement on the best way to treat vital permanent teeth with cariously exposed pulp (1, 2). It has been claimed that pulpectomy is the most suitable treatment for preventing and/or healing apical periodontitis (3, 4). It has been clearly shown that root canal treatment on teeth with vital pulp gives a reliable outcome (5, 6). However, the prognosis in term of survival rate of endodontically treated teeth is not as good as vital teeth, especially in molars (hazard ratio, 7:1) (7). The possible reasons could include the loss of proprioceptive function (8), damping property (9), and tooth sensitivity, which are provided by vital pulp as a defensive mechanism from harmful stimuli. Therefore, the vital pulp should be preserved if possible.

It has been recommended that vital pulp therapy, namely direct pulp capping, partial pulpotomy, or full pulpotomy, should be performed only in teeth with reversible pulpitis with no periapical pathologies or in teeth with either mechanical pulp exposure or recently traumatic pulp exposure (10–12). The problem is how we can accurately assess whether the status of the pulp is reversible or irreversible. The clinical signs and symptoms such as degree or characteristic of pain do not precisely reflect the pulp condition (13–15). The vitality test, for example, thermal test or electric pulp test, reveals only a yes or no response (13, 16). Currently, several studies have reported successful outcome of vital pulp therapy in vital teeth with cariously exposed pulp with signs and symptoms of irreversible pulpitis with periapical lesions (17–20).

Decision-making when approaching clinical problems should be based on the best currently available evidence. Systematic review consists of collecting unbiased data systematically and reevaluation by meta-analysis of relevant articles. This approach is considered to provide the highest level of evidence (21).

The aim of this study was to perform a systematic review to illustrate the clinical and radiographic success of each treatment procedure, namely direct pulp capping, partial pulpotomy, and full pulpotomy, in vital permanent teeth with cariously exposed pulp.

Materials and Methods

Literature Search

Searching strategy (Table 1) was conducted independently by 2 reviewers (P.A., P.L.) via MEDLINE via Ovid, PubMed, and the Cochrane database.

Seven textbooks including *Principles and Practice of Endodontics* (Torabinejad and Walton, 4th ed, 2008), *Pathways of the Pulp* (Cohen and Hargreaves, 9th ed, 2006), *Endodontics* (Ingle, Bakland, and Baumgartner, 6th ed, 2008), *Textbook of Endodontology* (Bergenholtz, Horsted-Bindslev, and Reit, 2nd ed, 2010), *Endodontics* (Stock, Waler, and Gulabivala, 3rd ed, 2004), *Essential Endodontology* (Ostarvik and Pitt Ford, 2nd ed, 2008), *Pulp-Dentin Biology in Restorative Dentistry* (Mjör, 1st ed, 2002), *Seltzer and Bender's Dental Pulp* (Hargreaves and Goodis, 3rd ed, 2002), and 5 endodontic-related journals (*International Endodontic Journal*, *Journal of Endodontics*, *Oral Surgery Oral Medicine Oral Pathology Oral Radiology Endodontology*, *Dental Traumatology*, and *Australian Endodontic Journal*) were handsearched. Finally, reference lists of relevant articles from both electronic search and hand search were screened again.

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TRIALS

STUDY PROTOCOL Open Access

Selective or stepwise removal of deep caries in deciduous molars: study protocol for a randomized controlled trial

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Abstract

Background: For treating deep caries lesions, selective or stepwise (one- and two-step) incomplete excavation seems advantageous compared with complete caries removal. However, current evidence regarding the success, as defined by not requiring any retreatments, or survival of teeth after different excavations is insufficient for definitive recommendation, especially when treating deciduous teeth. Moreover, restoration integrity has not been comparatively analyzed longitudinally, and neither patients', dentists' or parents' preferences nor the clinical long-term costs emanating from both initial and retreatments have been reported yet.

Methods/Design: The planned study is a prospective multicenter, two-arm parallel group, randomized controlled clinical trial comparing selective and stepwise excavation in deciduous molars with deep, active caries lesions without pulpal symptoms. We will recruit 300 children aged between three and nine-years-old with a minimum of one such molar. Patients participating in another study, or those with systemic diseases, disabilities or known allergies to used materials as well patients with teeth expected to exfoliate within the next 18 months will be excluded. After inclusion, sequence generation will be performed. Initial treatment will follow dental routine. During excavation, leathery, moist and reasonably soft dentin will be left in proximity to the pulp followed by adhesive restoration of the cavity. Afterwards, patients', dentists' and parents' subjective assessment of the treatment will be recorded using visual analogue or Likert scales. Re-examination will be performed after six months, and only then teeth will be allocated to one of the two interventions. Selectively excavated teeth will not be treated further, whilst for stepwise caries removal, a second excavation will be performed until only hard dentin remains. Clinical re-evaluations will be performed after 12, 24 and 36 months. Restorations will be reassessed using modified Ryge criteria. Objectively or subjectively required retreatments will determine success and survival. Retreatments will be evaluated both subjectively and regarding generated costs.

Discussion: Based on the results of the trial, decision-making for treating deep caries lesions in deciduous molars based on multiple criteria should be feasible.

Trial registration: Clinicaltrials.gov identifier: NCT02232828 (registered on 29 November 2014).

Keywords: Caries, Costs, Dentin, One-step excavation, Partial excavation, Two-step excavation

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European Journal of
Oral Sciences

Treatment of deep caries lesions in adults: randomized clinical trials comparing stepwise vs. direct complete excavation, and direct pulp capping vs. partial pulpotomy

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Bjørndal L, Reit C, Bruun G, Markvart M, Kjældgaard M, Näsman P, Thordrup M, Dige I, Nyvad B, Fransson H, Lager A, Ericson D, Petersson K, Olsson J, Santimano EM, Wennström A, Winkel P, Gluud C. Treatment of deep caries lesions in adults: randomized clinical trials comparing stepwise vs. direct complete excavation, and direct pulp capping vs. partial pulpotomy. Eur J Oral Sci 2010; 118: 290–297. © 2010 The Authors. Journal compilation © 2010 Eur J Oral Sci

Less invasive excavation methods have been suggested for deep caries lesions. We tested the effects of stepwise vs. direct complete excavation, 1 yr after the procedure had been carried out, in 314 adults (from six centres) who had received treatment of a tooth with deep caries. The teeth had caries lesions involving 75% or more of the dentin and were centrally randomized to stepwise or direct complete excavation. Stepwise excavation resulted in fewer pulp exposures compared with direct complete excavation [difference: 11.4%, 95% confidence interval (CI) (1.2; 21.3)]. At 1 yr of follow-up, there was a statistically significantly higher success rate with stepwise excavation, with success being defined as an unexposed pulp with sustained pulp vitality without apical radiolucency [difference: 11.7%, 95% CI (0.5; 22.5)]. In a subsequent nested trial, 58 patients with exposed pulps were randomized to direct capping or partial pulpotomy. We found no significant difference in pulp vitality without apical radiolucency between the two capping procedures after more than 1 yr [31.8% and 34.5%; difference: 2.7%, 95% CI (−22.7; 26.6)]. In conclusion, stepwise excavation decreases the risk of pulp exposure compared with direct complete excavation. In view of the poor prognosis of vital pulp treatment, a stepwise excavation approach for managing deep caries lesions is recommended.

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Key words: caries removal; endodontics; pulp exposure; randomized clinical trial; stepwise excavation

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Deep caries induces severe inflammatory reactions in the pulp and may cause pulp necrosis. When deep caries lesions are excavated, the dentin barrier may be broken and the healing of the pulp impaired. It has been suggested that a stepwise approach to caries excavation, as opposed to a direct complete excavation, would decrease the number of pulp exposures and accordingly enhance the possibilities for the pulp to heal (1, 2). A Cochrane review (3) found only two trials that compared stepwise excavation vs. direct complete excavation with respect to pulp exposure. Magnusson & Sundell (1) found an advantage of stepwise excavation: only 15% of the pulps were exposed compared with 53% after complete excavation. Similar findings were reported by Leksell *et al.* (2) (18% vs. 40%). The teeth treated were either primary molars (1) or young permanent teeth in children (mean age 10 yr) (2). Whether these results are applicable to an adult population is unknown. Both trials used pulp exposure as the outcome measure and did not report on treatment of the exposed pulps or on sustained pulp vitality. Also, for a proper comparison between the outcomes of stepwise vs. complete caries excavation, randomized clinical trials are needed to improve the evidence concerning the treatment of deep caries (3–7).

The exposed pulp has been the subject of numerous studies, but well-designed clinical trials on the treatment of caries-exposed pulps in adult teeth are scarce (8). In a large cohort study with up to 12 yr of follow-up, Nyborg (9) reported 58% success in direct pulp capping with calcium hydroxide as the capping material in patients older than 15 yr of age. Shovelton *et al.* (10) showed that the 2-yr success rate following direct pulp capping varied between 50 and 80%, depending on the pulp condition and the materials used. Retrospective studies indicate that there is a difference in treatment success between the traumatically exposed pulp and the pulp exposed during caries excavation. For example, Al-Hiyasat *et al.* (11) found that direct capping of traumatically exposed pulps with calcium hydroxide was successful in 92% of treatments after a 3-yr follow-up

RESEARCH REPORTS
Clinical

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Randomized Trial of Partial *vs.* Stepwise Caries Removal: 3-year Follow-up

ABSTRACT

This randomized, multicenter clinical trial evaluated the effectiveness of 2 treatments for deep caries lesions — partial caries removal (PCR) and stepwise excavation (SW) — with respect to the primary outcome of pulp vitality for a 3-year follow-up period. Inclusion criteria were as follows: patients with permanent molars presenting deep caries lesions (lesion affecting ≥ 1/2 of the dentin on radiographic examination), positive response to a cold test, absence of spontaneous pain, negative sensitivity to percussion, and absence of periapical lesions (radiographic examination). Teeth randomly assigned to PCR (test) received incomplete caries removal and filling in a single session. Outcome success was evaluated by assessment of pulp vitality, determined by pulp sensitivity to a cold test and the absence of periapical lesions. Data were analyzed by a Weibull regression model with shared frailty term (survival analysis). At baseline, 299 treatments were executed: PCR, 152 and SW, 147. By the end of the 3-year follow-up period, 213 teeth had been evaluated. Adjusted survival rates were 91% for PCR and 69% for SW ($p = 0.004$). These results suggest that there is no need to re-open a cavity and perform a second excavation for pulp vitality to be preserved (Clinical trials registration NCT00887952).

KEY WORDS: dental caries, clinical trial, permanent dentition, survival analysis, permanent dental restoration, dental pulp.

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INTRODUCTION

The treatment of asymptomatic teeth presenting deep caries lesions is usually based on traditional techniques that involve the complete removal of the soft, demineralized dentin. In these cases, it is common to have the pulp exposed during the operative procedure (Magnusson and Sundell, 1977; Leksell *et al.*, 1996; Ricketts *et al.*, 2006). Previous investigations have shown that conservative treatments of the exposed pulp resulted in a poor prognosis in follow-up trials (Barthel *et al.*, 2000; Bjørndal *et al*., 2010).

Stepwise excavation (SW) is an option for the treatment of deep lesions. It involves initial excavation, in which the necrotic and disorganized tissue is removed, leaving soft tissue over the pulp wall. The cavity is then temporarily sealed, allowing the pulp to react and produce tertiary dentin (Bjørndal, 2008). The cavity is subsequently re-opened, and the remaining demineralized dentin is removed. This technique involves less pulp exposure compared with complete caries removal during a single session (Magnusson and Sundell, 1977; Leksell *et al*., 1996). One-year evaluation of SW revealed a survival rate of 74 to 91% (Bjørndal and Thylstrup, 1998; Bjørndal *et al*., 2010). However, SW requires 2 sessions for treatment completion, resulting in additional costs and discomfort to the patient; further, there is a probability of pulp exposure during the second procedure (Bjørndal and Thylstrup, 1998; Bjørndal *et al*., 2010).

Because of these problems and the evidence pertaining to lesion arrest after sealing of the cavity (Bjørndal and Larsen, 2000; Maltz *et al.*, 2002; Alves *et al.*, 2010), there is discussion in the literature concerning the necessity for cavity re-opening (Ricketts *et al*., 2006). Three clinical trials have studied partial caries removal (PCR) on permanent teeth: Two of these trials included lesions reaching the outer half of dentin (Mertz-Fairhurst *et al*., 1998; Bakhshandeh *et al*., 2011), and the third involved lesions reaching the inner half of dentin (Maltz *et al*., 2011). All of these studies reported no detrimental effects when demineralized tissue was left in the cavity. Despite these, there are no long-term randomized, controlled trials that support a 1-step partial excavation followed by the immediate placement of a filling on permanent teeth.

The aim of this randomized, multicenter trial was to compare PCR and SW with respect to the primary outcome of pulp vitality for a 3-year follow-up period.

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Conventional caries removal and sealed caries in permanent teeth: A microbiological evaluation

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ABSTRACT

Objectives: The aim of this study was to compare microbiological infection after conventional carious dentine removal with incomplete carious dentine removal and sealing.
Methods: Eighty-seven patients (12–50 years of age) under treatment at the Dental Clinics of the Federal University of Rio Grande do Sul (UFRGS), Brazil, participated in the study. The patients presented 90 posterior permanent teeth with primary caries. The lesions were coronal, active, and reached at least the middle third of the dentine. None of the teeth exhibited spontaneous pain, sensitivity to percussion or apical pathology (detected through radiographic exams). Pulp sensibility was confirmed by the cold test. The lesions were divided into 2 experimental groups: complete caries removal (CCR) based on hardness criteria ($n = 60$ lesions) and incomplete caries removal (ICR) and sealing ($n = 32$ lesions). Microbiological samples were obtained from the initial demineralized dentine, after CCR and after ICR-Seal.
Results: The number of anaerobic and aerobic bacteria, lactobacilli, and mutans streptococci decreased at the end of treatment ($p < 0.05$). Significantly less anaerobic bacteria ($p < 0.01$), aerobic bacteria ($p = 0.02$), and mutans streptococci ($p < 0.01$) growth was observed after ICR-Seal compared to CCR. The difference in lactobacilli was insignificant ($p = 0.08$). The amount of bacteria detected after conventional caries removal was higher than that which remained in sealed caries lesions.
Conclusions: The results suggest it is not necessary to remove all carious dentine before the restoration is placed because over time, sealing of carious dentine results in lower levels of infection than traditional dentine caries removal.
Clinical significance: The results of this study indicate that sealed carious dentine was less infected than the remaining dentine left after conventional caries removal and sealing. Our results support treatment of deep carious lesions in one session with incomplete removal of carious dentine.

1. Introduction

Carious dentine removal is an important step in the restoration process. Microorganisms beneath the restoration are believed to be the main cause of restoration failure.[1]

There is a high risk of pulp exposure if all the decayed tissue is removed in deep carious lesions.[2,3] One possible treatment for exposed pulp is direct pulp capping; however, the success rate for preserving tooth vitality is very low if this procedure is performed in the presence of decayed tissue.[3–5] An alternative

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Clinical and Ultrastructural Effects of Different Liners/Restorative Materials on Deep Carious Dentin: A Randomized Clinical Trial

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Key Words
Calcium hydroxide · Carious dentin · Deep carious lesions · Glass ionomer cement · Stepwise excavation

Abstract
We evaluated the effect of calcium hydroxide cement (CHC) and glass ionomer cement (GIC) on carious dentin and bacterial infections after partial caries removal and sealing. Sixty permanent teeth with deep lesions underwent partial caries removal, the application of CHC, GIC or wax, i.e. negative control (NC), and were then sealed for 3–4 months. After the partial caries removal and the sealing period, the dentin was clinically assessed (colour and consistency) and analysed by scanning electron microscopy to assess dentin organization and bacterial infections. The effect of the treatment in each group was assessed by the Wilcoxon and χ^2 tests, differences among groups by the Kruskal-Wallis test and the correlations between variables by Spearman correlation. No clinical symptoms or radiographic signals of pulpits or pulp necrosis were observed during the study. Dentin darkening was observed after the sealing period in the CHC and NC groups ($p < 0.05$). However, there was no difference in the colour after treatment among the 3 groups ($p > 0.05$). Dentin hardening occurred in all groups after treatment ($p < 0.05$), also with no differences ($p > 0.05$). Dentin samples showed better organization after the sealing period than after partial caries removal, with total or partial obliteration of dentinal tubules (CHC $p < 0.03$, GIC $p < 0.05$, NC $p < 0.01$) and a reduction of bacterial infections (CHC $p < 0.03$, GIC $p < 0.05$, NC $p < 0.03$). No differences were observed. Correlations between the different criteria, except for colour and bacterial infection, were detected in all cases. Partial caries removal and sealing resulted in dentin hardening, decreased bacterial numbers and dentin reorganization, irrespective of the dentin protection used.

Stepwise excavation has been widely used in the treatment of deep carious lesions to prevent pulp exposure [Magnusson and Sundell, 1977; Leksell et al., 1996; Bjørndal et al., 2010]. This approach consists of preserving a layer of carious dentin over the pulp. A protective liner is then applied, and the tooth is sealed for a certain period of time. The purpose of this procedure is to promote the formation of tertiary dentin before the complete excavation, thus making pulp exposure less likely [Kidd, 2004].

The covering of the innermost layer of carious dentin with a protective liner has been extensively discussed. Calcium hydroxide cement (CHC) and glass ionomer cement (GIC) have been commonly applied on carious dentin to induce remineralisation. CHC is often the preferred cement for pulp protection because it is alkaline and biocompatible, induces pulp-dentin remineralisation and reduces the risk of bacterial infection [Eidelman et al., 1965; Aponte et al., 1966; Leung et al., 1980; Bjørndal et

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An Ultraconservative Method for the Treatment of Deep Carious Lesions-*Step wise Excavation*

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Abstract: Deep dentinal lesion progress is often presented as the point of no return for the specific pulp involved. In these lesions, however large variations and changes within the lesion environment may be detected.[5] As the disease process is better studied and understood, more conservative treatments have come up in the treatment of deep carious lesions. One such is a step-wise excavation procedure, which is minimally invasive and reduces the risk of pulp exposure.

Key words: Stepwise excavation · Indirect pulp capping · Deep carious lesion

INTRODUCTION

Currently modern dentistry is in an era of minimal intervention for maximum preservation of tooth structure and function. Caries management has shifted its focus more towards prevention and control of the disease because of a better understanding of the basic disease process and advances in dental material science. The management of deep dentinal caries still poses a major challenge to the restorative dentist because there is no infallible way to predict the future development of the lesion.

The philosophy of deep caries management can be traced back to two thoughts: according to the first school of thought, G.V.Black[1] (1908) proposed that it was better to expose the pulp of a tooth than to leave it covered only with softened dentin. The second school of thought, on the contrary, by Tomes[1] suggested that a layer of discoloured dentin should be allowed to remain for the protection of pulp rather than running the risk of sacrificing the tooth. This subject even today has been dominated by much contradictory and controversial information.

Indirect Pulp Capping: This technique was proposed by Eidelmann *et al* in 1965. This is the most common but rather radical approach, which has the inherent risk of pulp exposure, necessitating the need for endodontic treatment and has the advantage of being a one-step procedure.

Step-wise Excavation: It is a two-step excavation procedure that has been advocated by Magnusson and Sundell (1977) and has been recently modified by Bjorndall (1997). This procedure is less invasive and aims at reducing the risk of pulp exposure.[2] The main difference is that the indirect pulp capping procedure almost completely removes the affected dentin and re-entry is not made (one-step procedure), while the step-wise excavation procedure involves re-entry at varying intervals.

Procedure

Selection Criteria:

- Clinically detected deep carious lesion (Fig 1)
- 75% radiographic dentin involvement (Fig 2)
- No history of spontaneous pulpal pain
- Positive pulp vitality to all tests
- No radiographic evidence of periapical lesion

Steps

First Excavation: Under anesthesia and rubber dam isolation, access cavity is prepared using a high speed rotary bur with water coolant. Peripheral excavation of soft caries on the walls of the cavity is carried out initially

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Long-term Survival of Indirect Pulp Treatment Performed in Primary and Permanent Teeth with Clinically Diagnosed Deep Carious Lesions

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Abstract

Introduction: This retrospective study examined clinically and radiographically the 3-year survival of teeth treated with indirect pulp treatment (IPT) performed between 2000 and 2004. **Methods:** Sixty-six uncooperative children (4-18 years old) with at least one tooth with clinically diagnosed deep caries were included. Radiographically, the lesion depth was greater than two thirds of the dentin thickness. Incomplete excavation was performed leaving infected carious dentin at the center of the cavity. After placement of a layer of resin-modified glass ionomer as liner, the teeth were restored. A 3-year survival analysis (Kaplan-Meier) was performed. Failure was defined as the presence of either a clinical symptom (pain, swelling, or fistula) or radiologic abnormality at recall. In total, 86 of 125 (69%) treated primary molars and 34 of 45 (76%) treated permanent teeth were available for both clinical and radiographic evaluation. **Results:** The survival rate was 96% for primary molars (mean survival time, 146 weeks) and 93% for permanent teeth (mean survival time, 178 weeks). **Conclusion:** This study shows that IPT performed in primary and permanent teeth of young patients may result in a high 3-year survival rate. *(J Endod 2010;36:1490–1493)*

Key Words

Caries detector, caries management, deep caries, indirect pulp capping, indirect pulp therapy, indirect pulp treatment, infected dentin, resin-modified glass ionomer, ultraconservative caries treatment

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The discussion of how much carious dentin must be removed in order to arrest the carious process exists already more than 150 years (1). With reference to the outcome of the histologic studies of Reeves and Stanley (2), infected dentine should be completely removed in order to arrest the carious process. However, it has been reported that carious progression was arrested for at least 10 years when bonded, and sealed composite restorations were placed directly over frank cavitated lesions extending into the dentin (3). Therefore, complete dentine carious removal may not be a prerequisite to arrest carious progression (4, 5). A randomized clinical trial with the "Hall technique," in which there is no carious excavation, showed that caries is a disease that will arrest in the right circumstances (6). Taking into account the beneficial outcome in five clinical studies (7), indirect pulp treatment (IPT) is recommended as an appropriate procedure for treating primary teeth with deep carious lesions and asymptomatic pulp inflammation provided that the restoration seals the cavity properly. In summary, the traditional concept of complete carious removal has been challenged.

With IPT, carious dentin near the pulp is preserved to avoid pulp exposure and is covered with a biocompatible material (8). Pulpal inflammation is inevitable once the dentin is affected. The remaining dentin thickness after carious excavation is a key determinant regarding the state of the pulp (9, 10). There is poor correlation, however, between the histologic findings and the clinical diagnosis of pulpal injury. Subjacent to deep carious lesions, the pulp presents chronic inflammatory exudates, including lymphocytes, macrophages, and plasma cells (11), indicating that pulpitis has been developed even in absence of unprovoked pain. On the other hand, for many years, the importance of inflammation in maintaining pulpal health has been underestimated. Inflammation was considered an undesirable side effect, frequently leading to pulp necrosis. In view of recent results, the inflammatory process should be re-examined to understand its potentially beneficial effect on pulp regeneration (12). Despite extensive pulpal inflammation because of deep caries, a conservative approach can still generate a favorable prognosis for pulpal repair.

When pulp exposure has occurred during complete excavation in primary or young permanent teeth, (partial) pulpotomy is a treatment option for teeth diagnosed with reversible pulpitis (7, 13). In case of symptoms referring to irreversible pulpitis, such as unprovoked pain, vital pulp techniques are associated with poor clinical outcomes. In those cases, vital pulpectomy is usually needed to save the tooth. Because of the difficulties in cleaning and filling morphologically complex root canal systems, the placement of a root canal filling does not always prevent coronal bacterial contamination (14, 15). As a result, in some cases, periapical lesions may emerge. In previous outcome studies and systematic reviews, the average success rate for root canal therapy performed in teeth with vital pulps is rather high (16–18). In Toronto studies, a success rate of 93% was recorded (17). Interestingly, many outcome studies reported both periapical index scores 1 and 2 as "healed" or "successful" (17, 19) despite score 2 representing mild periapical inflammation (20). When score 2 would not be considered "successful," the success rate for vital teeth would drop to 70% (21). In animal studies (22–24), posttreatment apical periodontitis was present in a high percentage of teeth up to 12 months after performing vital pulpectomy.

Recent studies showed IPT-treated teeth remaining symptomless and free of radiologic abnormalities for years (5, 7). The pulp maintains its healing potential and

Operative caries management in adults and children (Review)

Ricketts D, Lamont T, Innes NPT, Kidd E, Clarkson JE

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Outcomes of Direct Pulp Capping by Using Either ProRoot Mineral Trioxide Aggregate or Biodentine in Permanent Teeth with Carious Pulp Exposure in 6- to 18-Year-Old Patients: A Randomized Controlled Trial

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Abstract

Introduction: This study aimed to compare the success rates of direct pulp capping (DPC) by using either ProRoot Mineral Trioxide Aggregate (MTA) or Biodentine in the cariously exposed permanent teeth of 6- to 18-year-old patients. Gray discoloration was also evaluated. **Methods:** Fifty-nine cariously exposed permanent teeth, including teeth with diagnosis of normal pulp, reversible pulpitis, or irreversible pulpitis, early periapical involvement, and exposure size of up to 2.5 mm, were included. Each patient with only 1 cariously exposed tooth was randomly allocated to DPC with either ProRoot MTA ($n = 30$) or Biodentine ($n = 29$). Patients were recalled every 6 months. Clinical and radiographic examinations were used to determine success. **Results:** Fifty-five patients (mean age, 10 ± 2 years), 27 treated with ProRoot MTA and 28 with Biodentine, were included in the analysis. At mean follow-up of 18.9 ± 12.9 months, the success rate was 92.6% with ProRoot MTA and 96.4% with Biodentine ($P > .05$; difference, 4%; 95% confidence interval [CI], –8% to 16%). Biodentine was non-inferior to ProRoot MTA. Failures were distributed equally in all categories of pulpal diagnosis and occurred in teeth with no periapical involvement and small exposures (0.5 mm). The survival probabilities of DPC with ProRoot MTA and Biodentine were 0.92 (95% CI, 0.73–0.98) and 0.96 (95% CI, 0.80–0.99). No significant difference was observed between them ($P > .05$). Gray discoloration was observed only with ProRoot MTA (55%). **Conclusions:** Biodentine was non-inferior to ProRoot MTA when used as a DPC material for cariously exposed permanent teeth of 6- to 18-year-old patients. However, Biodentine did not cause any gray discoloration in this study. *(J Endod 2017;■:1–8)*

Key Words

Biodentine, cariously exposed, direct pulp capping, permanent teeth, ProRoot MTA

Significance

ProRoot MTA and Biodentine can be used as a DPC material. Biodentine did not cause discoloration. Teeth with carious exposure, irreversible pulpitis, or early periapical involvement or exposures up to 2.5 mm should not be absolute contraindications for DPC.

Promising evidence of the success of direct pulp capping (DPC) has increased tremendously during the past few decades. One of the reasons behind this increased success is the introduction of the first calcium silicate cement (CSC), gray mineral trioxide aggregate (MTA), by Torabinejad and Chivian (1) in the 1990s. MTA appears to be more effective than calcium hydroxide (CH) in maintaining long-term pulp vitality (2). Favorable properties of MTA include significant reduction in pulpal inflammation and improved dentin bridge quality (2). However, MTA has many disadvantages, including long setting time, poor handling properties, high cost, and the potential for tooth discoloration (3, 4). Although white MTA was later developed to overcome the severe discoloration caused by the original gray MTA, one study found tooth discoloration in 13.6% of cases after DPC (5). Tooth discoloration can be problematic, especially in the esthetic region, resulting in more complicated procedures such as internal bleaching, which can jeopardize the vitality of the tooth (6). Moreover, the discolored tooth may be incorrectly recognized as a necrotic tooth.

Continued searching for alternatives has been ongoing for some time. In 2009, Biodentine, a new CSC with the same active by-product (CH) to that of MTA, was

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ORIGINAL ARTICLE

Long-term evaluation of direct pulp capping—treatment outcomes over an average period of 6.1 years

Till Dammaschke · Jana Leidinger · Edgar Schäfer

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Abstract To assess the treatment outcomes of direct pulp capping with calcium hydroxide, 248 teeth were examined 0.4–16.6 years (mean, 6.1±4.4) after pulp capping. Only teeth diagnosed to be clinical healthy or with spontaneous pain were capped. The treatment outcome was assessed by interviewing for signs or symptoms responsiveness and sensibility testing with CO_2. The overall survival rate was 76.3% after 13.3 years. Of the teeth, 80.2% were found to have a favourable treatment outcome. The pulps of 60-year-old patients showed a significant lower favourable treatment outcome when compared to patients younger than 40 years ($p<0.05$). The treatment outcome was significantly less favourable in teeth restored with glass ionomer cement compared to all other teeth ($p<0.01$). The likelihood to show an unfavourable treatment outcome after direct pulp capping was significantly higher for teeth with spontaneous pain than for teeth with clinically healthy pulps ($p<0.001$). In addition, the likelihood for a tooth to become non-vital after direct pulp capping was significantly higher within the first 5 years after treatment than after more than 5 years ($p<0.001$) after treatment.

Keywords Calcium hydroxide · Direct pulp capping · Long-term evaluation · Treatment outcome

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Introduction

Direct pulp capping is defined as wound dressing of exposed vital pulp tissue. The exposure can occur due to caries excavation or trauma. Usually, the pulp and dentine wound is treated with calcium hydroxide in order to protect the injured tissue, to induce the formation of reparative dentine, and to keep the tissue vital. The overall aim of direct pulp capping is pulp healing [1–3]. Several months after direct pulp capping, the following effects can be expected:

- Regular pulp tissue without signs of inflammation and with a constant layer of reparative dentine
- Chronically inflamed and infiltrated pulp tissue with a permeable layer of reparative dentine interspersed with tunnel defects
- Highly inflamed pulp tissue with an imperfect, incomplete or missing layer of reparative dentine or a dense collageneous scar tissue in the area of pulp perforation.

Only the first condition is regarded as successful pulp healing because only in this case the pulp tissue will survive, hold off and regenerate after prospective damages and irritations [4].

The advantage of a tooth with a directly capped and vital pulp is mainly the protective resistance to the force of mastication. A root canal treated tooth requires 2.5 times more load to register a proprioceptive response than a vital tooth [5]. Thus, the protection from hard tissue damage caused by mastication forces is superior in a tooth with a vital pulp when compared with a root-canal-filled tooth. Furthermore, direct pulp capping is a non-invasive, comparatively simple and inexpensive treatment, which does not require complex and costly restorations [6].

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Pulpotomy of Symptomatic Permanent Teeth with Carious Exposure Using Mineral Trioxide Aggregate

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ABSTRACT

Introduction: To evaluate the clinical and radiographic outcomes of pulpotomy treatment with mineral trioxide aggregate (MTA) in symptomatic mature permanent teeth with carious exposure. **Materials and Methods:** Ten patients aged 27-54 years presented with 11 symptomatic permanent teeth (*n*=11). Each offending carious tooth was clinically and radiographically determined. We removed caries as conservatively as possible; however pulp exposure was inevitable. ProRoot MTA pulpotomy was performed on these teeth. The patients were followed-up clinically and radiographically for 24-42 months. **Results:** Immediate relief of patients` symptoms occurred. Moreover, teeth responses to the electric pulp tester were within normal range on follow-up appointment and the radiographs did not reveal any abnormality/lesion in the periapical areas. **Conclusion:** Pulpotomy using MTA could be a good alternative for root canal therapy (RCT) for managing symptomatic mature permanent teeth with carious exposure, however further large-scale multicenter clinical trials are highly encouraged to confirm this hypothesis.

Keywords: Dental Pulp Exposure; Endodontic; Mineral Trioxide Aggregate; Permanent Dentition; Pulpotomy, Root Canal Therapy

1. Introduction

Vital pulp therapies aim to maintain tooth vitality, and functionality and to render the tooth asymptomatic [1]. Pulpotomy, for instance, is a procedure in which the coronal pulp that presumed to be inflamed and/or infected is surgically removed, and the remaining radicular dental pulp is covered at the orifices with a suitable material that protects the pulp from further injury and permits and promotes healing [2, 3]. Traditionally, the term "pulpotomy" has implied removal of the pulpal tissue to the cervical line, to be differentiated from "Cvek type" pulpotomy or "partial pulpotomy" in which just a portion of the coronal pulp is removed [4]. Indications of pulpotomy include primary teeth with irreversible coronal pulpitis or exposed vital pulps. Pulpotomy is considered as a treatment for immature permanent teeth with pulp exposure due to caries or trauma that gives evidence of extensive coronal pulpitis, and also as an emergency procedure for permanent mature teeth until root canal treatment can be accomplished [2].

Disagreement exists concerning pulp capping and pulpotomy as a permanent treatment option in mature permanent teeth. It is universally accepted; however, that vital pulp therapy is indicated for pulp exposure in teeth with incompletely formed roots. But once root formation has been completed, root canal therapy (RCT) should be performed [2]. The best root canal filling is the healthy pulp tissue, and it should not be assumed that every damaged pulp must be extirpated and that pulp conservation is not satisfactory procedure [5]. However, pulp exposure due to deep caries, in particular, normally results in the mature tooth requiring RCT. It is the only procedure which insures removal of the bacteria that invaded the pulp [6].

MTA has attracted attention since its introduction to the field of endodontics [7]. It has a lot of advantages compared to other conventional endodontic materials; *e.g.* its excellent sealing ability [8], biocompatibility [9], dentin bridge formation in cases of pulp capping [10, 11] and pulpotomy [12] in addition to inducing proliferation of the pulpal cells [13]. Although many studies showed that MTA is the material of choice for vital pulp therapy in primary and young permanent teeth, [14-17] other studies found no significant differences [18, 19].

Studies regarding the management of carious exposure in mature (fully developed) teeth are scare and conflicting. Accordingly, the aim of this clinical trial was to evaluate the clinical and radiographic outcomes of mineral trioxide aggregate (MTA) pulpotomy as permanent treatment of symptomatic mature permanent teeth with carious exposure.

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Should pulp chamber pulpotomy be seen as a permanent treatment? Some preliminary thoughts

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Abstract

Simon S, Perard M, Zanini M, Smith AJ, Charpentier E, Djole SX, Lumley PJ. Should pulp chamber pulpotomy be seen as a permanent treatment? Some preliminary thoughts. *International Endodontic Journal*, **46**, 79–87, 2013.

Aim To investigate the benefits of pulpotomy (to the level of the floor of the pulp chamber) as an endodontic treatment for teeth with vital pulps.

Methodology Seventeen patients, aged 7–54 years (mean of 37.2 year), were treated by pulpotomy and filling with ProRoot MTA® in premolar or molar teeth with vital pulps and without clinical evidence of irreversible pulpitis. The patients were then followed up for 12 to 24 months and the teeth then assessed by clinical and radiographic examination. Statistical analysis was performed with Kaplan–Meier survival probability statistics to estimate the survival of the treated teeth.

Results At 24 months, the survival rate without any complementary treatment was estimated to be 82%. Two of the 17 treated teeth required root canal treatment for pain control and one for prosthetic reasons.

Conclusions Under the conditions of this study, pulpotomy offered a viable alternative to root canal treatment for teeth with vital pulps in the short term. However, there is insufficient clinical evidence to consider this technique for the treatment of every permanent tooth. Nevertheless, it should be considered as a potential alternative approach to be further developed for future applications.

Keywords: inflammation, mineral trioxide aggregate, pulp capping, pulpotomy.

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Introduction

Endodontic technology has evolved greatly over the past two decades. The introduction of nickel-titanium rotary instrumentation, new root filling devices, operating microscopes and accurate apex locators has considerably improved the quality of endodontic care. However, endodontics still remains one of the most challenging dental specialties, because of the technical complexities of treatment procedures.

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Increasing demand for endodontic re-treatment arising from a significant number of unsuccessful initial root canal treatment procedures and a high prevalence of periapical disease (Figdor 2002) provides appreciable clinical challenges. However, various technical developments within endodontics have broadened the scope of application of these technologies and allow more teeth to be saved than might previously have been achieved with consequent improvements in treatment outcomes. Despite these improvements, conventional root canal treatment is a complicated, time-consuming and expensive process, particularly in general practice where the outcomes of root canal treatment are often poor (Boucher *et al.* 2002). Regenerative approaches to endodontic

Cariously exposed pulps may benefit from vital pulp therapies

A critical summary of Aguilar P, Linsuwanont P. Vital pulp therapy in vital permanent teeth with cariously exposed pulp: a systematic review (published online ahead of print March 5, 2011). J Endod 2011;37(5):581-587. doi:10.1016/j.joen.2010.12.004.

L. Virginia Powell, DMD

Systematic review conclusion. Dentists can treat permanent teeth with cariously exposed pulps successfully with vital pulp therapy.
Critical summary assessment. Preliminary evidence supports use of vital pulp therapy when pulps have carious exposure, with success rates ranging from 73 to 99 percent.
Evidence quality rating. Limited.

Clinical question. Are vital pulp therapies that involve the use of either calcium hydroxide (CH) or mineral trioxide aggregate (MTA) successful in maintaining pulp vitality in permanent teeth with carious exposures?

Review methods. Two reviewers searched three databases, several textbooks and reference lists of relevant articles for clinical studies published between January 1950 and May 2010. Inclusion criteria were treatment of carious permanent teeth; use of either CH or MTA as the medicament for direct pulp-capping, partial pulpotomy or full pulpotomy procedures; use of clinical and radiographic criteria to define success when measured after at least six months; and publication in the English language. The authors conducted assessments of risk bias for the selected articles, and they analyzed weighted pooled success rates in an attempt to identify influencing factors such as materials used and root development.

Main results. From the 63 abstracts the authors screened initially, they identified 14 articles for inclusion. They excluded 49 articles, the majority (n = 34) because those studies involved noncarious exposures. They added nine articles as a result of the hand search; the final total of relevant articles was 23. Four studies were randomized controlled trials, five were cohort studies and 14 were case series. The mean quality score (maximum score, 17 points) was 8.8 for direct pulp capping, 8.16 for partial pulpotomy and 9.14 for full pulpotomy. The total number of teeth analyzed was 1,385 (direct pulp capping, 996; partial pulpotomy, 199; full pulpotomy, 190). The long-term (more than three-year) weighted pooled success rates were 72.9 percent (95 percent confidence interval [CI], 49.6-96.3; n = 231) for direct pulp capping, 99.4 percent (95 percent CI, 95.6-103.2; n = 23) for partial pulpotomy and 99.3 percent (95 percent CI, 94.5-104.1; n = 37) for full pulpotomy. The authors deemed partial and full pulpotomy procedures statistically equivalent. Investigators in only three trials ran head-to-head comparisons of CH and MTA and noted no significant differences. When data were pooled, the authors found MTA to be significantly more successful in direct pulp capping procedures (n = 581) (90.5 percent versus 70.6 percent) and CH more effective in partial pulpotomy procedures (n = 269) (94.8 percent versus 87.5 percent). Again with pooled data, teeth with open apexes treated with direct pulp-capping procedures (n = 62) were more likely to survive than were teeth with closed apexes (n = 456) (94.5 percent versus 69.2 percent).

Conclusions. Vital pulp therapy is a viable alternative to pulpectomy when permanent teeth experience a carious exposure, and pulpotomy procedures are more effective than are pulp-capping procedures.

No sources of funding for this systematic review were listed.

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Randomized Clinical Trial to Evaluate MTA Indirect Pulp Capping in Deep Caries Lesions After 24-Months

U Koc Vural • A Kiremitci • S Gokalp

Clinical Relevance

The application of MTA and calcium hydroxide showed similar clinical performance over a 24-month period.

SUMMARY

Objective: This clinical study aimed to assess the efficacies of mineral trioxide aggregate (MTA) and calcium hydroxide [$Ca(OH)_2$] in the treatment of deep carious lesions by the direct complete caries removal technique.

Methods and Materials: A total of 100 permanent molar/premolar teeth were capped with either $Ca(OH)_2$ (n=49) or MTA (n=51) and restored with composite resin in 73 patients. Periapical radiographs were acquired prior to the treatment as well as at six, 12, and 24 months posttreatment. Two calibrated examiners performed the clinical and radiographic assessment of the periapical pathology and pulpal symptoms. Intergroup comparisons of the observed values were performed using the Fisher exact test. Significance was predetermined at $\alpha = 0.05$.

Results: The recall rates were 100% at six and 12 months posttreatment and 98.6% at 24 months posttreatment. Four teeth capped with $Ca(OH)_2$ (two each at six and 12 months posttreatment) and two capped with MTA (one each at 12 and 24 months posttreatment) received endodontic emergency treatment because of symptoms of irreversible pulpitis, which were clinically and/or radiographically established. There were no significant differences in pulp vitality between the two pulp-capping agents at six, 12, or 24 months posttreatment (p=0.238, p=0.606, and p=0.427, respectively).

Conclusions: Both pulp-capping materials were found to be clinically acceptable at 24 months posttreatment.

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INTRODUCTION

Infected deep carious lesions can be clinically managed either by preservation of the tooth tissue or by root canal therapy. Preservation of the dental pulp vitality is important in the treatment of deep

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Evaluation of indirect pulp capping using three different materials: A randomized control trial using cone-beam computed tomography

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Abstract

Objective: The objective of this study was to determine the most suitable material for indirect pulp treatment (IPT) clinically and to determine the thickness (in mm) and type of tissue in terms of radiodensity (in Hounsfield units [HU]) formed after pulp capping using cone-beam computed tomography (CBCT) scan. **Materials and Methods:** A longitudinal interventional single-blind randomized clinical trial was conducted on 94 children (7–12 years) with a deep carious lesion in one or more primary second molar and permanent first molar without the history of spontaneous pain indicated for indirect pulp capping (IPC) procedure. About 109 teeth were treated using three materials, namely, calcium hydroxide (setting type), glass ionomer cement (Type VII), and mineral trioxide aggregate randomly. The teeth were followed up at an interval of 8 weeks, 6 months, and 1 year for success of IPT as per the American Academy of Pediatric Dentistry clinical criteria. For determining the thickness and type of dentin tissue formed, a CBCT scan was done immediately postoperative and another scan at an interval of 6 months. The scans were compared to evaluate the average thickness of the dentin bridge formed. **Results and Conclusions:** Success rate for IPC was 96.85%. A significant difference was obtained in the average thickness of reparative dentin at immediate postoperative and 6-month postoperative values in all three groups suggesting distinct barrier formation. Similar significant findings were obtained in radiodensity of barrier formed (in HU). All three materials were found to be equally suitable as IPC agents suggesting mineral gain.

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Full Text

The treatment of deep carious lesions approaching healthy pulp has always been a challenge. Indirect pulp treatment (IPT) or indirect pulp capping (IPC) is recommended for teeth that have deep carious lesions approximating the pulp with no signs or symptoms of pulp degeneration.[1] This technique has been derived with the ideology that the dental pulp possesses the ability to form a dentin-like matrix (tertiary dentin) as a part of the repair in the dentin-pulp complex. The ultimate objective of IPT is to arrest the carious process by promoting dentinal sclerosis and stimulating promotion of reparative dentin with arresting demineralization of carious dentin while preserving the pulp vitality.[2]

Various materials have been used as IPC agents in the management of vital teeth with deep carious lesions. Calcium hydroxide has been a gold standard for pulp capping and is being used since its use was first described by Zander [3] in 1939. It allows the formation of a reparative dentin through cellular differentiation, extracellular matrix secretion, and subsequent mineralization.[4],[5] Various disadvantages such as gradual disintegration and formation of tunnel defects in the newly formed dentin have been commonly witnessed with calcium hydroxide when followed up for longer times.[6] This has led to the use of various other materials for IPC including glass ionomer cement and adhesives and more recently mineral trioxide aggregate (MTA).

As an ideal requirement in a vital pulp procedure, the remineralized tissue formed should be a thick structure resembling dentin so as to provide adequate protection to the pulp. The thickness and type of tissue formed during such procedures can only be judged by histologic studies.[7] However, this is not possible in vivo and can only be done after extraction or exfoliation of the teeth. Intraoral periapical radiographs or panoramic imaging technique were the only means by which the barrier formed after IPC could be assessed in vivo, but these have several limitations.[8] The problem of conspicuity, which is largely the result of two-dimensional representation of a three-dimensional (3D) structure, could be evidently seen with the use of radiographs. With the advent of time, when computed tomography (CT) scans became available for dental applications, various researchers have used it to improve the understanding of 3D properties of the jaw bones. Cone-beam CT (CBCT) is a new technology that uses a two-dimensional sensor and a cone-shaped beam in place of the fan-shaped X-ray beam used for conventional CT. It is capable of providing submillimeter resolution in images of high diagnostic quality, with short scanning times (10–70 s) and radiation dosages reportedly up to (25–30) times lower than those of conventional CT scans (head).[9],[10] Images provide X-ray attenuation information for specific sized image pixels/voxels in terms of Hounsfield units (HU), which are related to the grayscale. The previous literature indicates a tertiary dentin formation either detected through radiographs or after histological sectioning.[5],[6],[7] With the HU, it is probably possible to analyze the type and quantity of tissue formed with pulp capping in terms of radiodensity and thus predict the success of the procedure accurately. Thus, with this study, we attempted to compare the clinical outcome of IPT using three different materials, i.e., calcium hydroxide (setting type), glass ionomer cement (Type VII), and MTA after 1-year follow-up. As a secondary objective, we also proposed to study the radiodensity and thickness of the tissue formed using CBCT scan of the teeth after 6-month follow-up.

Materials and Methods

A longitudinal interventional randomized control trial was conducted on 7–12-year-old children attending the outpatient department of the Division of Pedodontics and Preventive Dentistry, CDER, AIIMS, New Delhi.

The pilot study aimed at evaluating the success of IPT and measurement of dentin barrier and its radiodensity using CBCT; a random sample of thirty in each group was selected making a total of ninety teeth. The duration of the study was 2 years which included subject recruitment, IPT treatment, and clinical/radiological follow-up at 8 weeks, 6 months, and 1 year.

Teeth with active deep caries on the occlusal or proximal surfaces with a history of dull, reversible pain, or mild discomfort on chewing were included in the study. On radiographic interpretation, caries depth should be greater than two-third of dentin thickness approaching pulp with no radiolucency in the periapical or furcation area of the teeth.[11] The inclusion criterion was based on the American Academy of Pediatric Dentistry (AAPD) guidelines (2010–2011).

Teeth with periodontal lesions, pathologic mobility, discoloration, with internal/external resorption and some of the acute/chronic systemic conditions which might affect the prognosis of the treatment were excluded from the study.

Teeth with deep caries in one or more mandibular primary second molars and permanent first molars were treated with IPC. The samples were allocated to the respective groups by following simple random sampling using a software generated sequence for serial number, i.e., in Group I, setting type calcium hydroxide (Dycal ® Ivory, Dentsply Caulk, Dentsply, L.D. Caulk, Milford, DE, USA) was used; in Group II, GIC (GC Fuji VII, Fuji, Tokyo, Japan) was used; and in Group III, MTA (ProRoot MTA; Dentsply Tulsa Dental Specialties, Dentsply International, Inc. USA) was used.

Patients were informed about the procedure and written informed consent was obtained before the procedure. A proforma was formulated for documenting patient's relevant diagnostic information, treatment, and treatment follow-up according to the AAPD guidelines (2010–2011).

All the procedures were performed by the standard method of IPT under rubber dam by a single operator. After satisfactory caries excavation, one of the test materials was applied at the base of the cavity according to manufacturer's instructions [Figure 1] and [Figure 2]. At this time, two half cut plastic beads were inserted just above the pulp capping material layer below final restoration of light-cure composite resin to serve as a marker for future measurements under CBCT scan. An immediate postoperative CBCT scan was performed the same day. At follow-up examination, detailed clinical and radiographic examination was performed after 8 weeks, 6 months, and at 1 year following the AAPD criteria for success of IPC (2011). After the procedure, all patients were instructed about prevention and maintenance of oral hygiene.{Figure 1}{Figure 2}

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ORIGINAL ARTICLE

Evaluation of the efficacy of calcium silicate vs. glass ionomer cement indirect pulp capping and restoration assessment criteria: a randomised controlled clinical trial—2-year results

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Abstract

Objectives Assess calcium silicate cement (Biodentine™) vs. glass ionomer cement (Fuji IX™, control) as indirect pulp capping (IPC) materials in patients with reversible pulpitis after a 2-year follow-up. Evaluate the integrity of the overlying resin composite restorations using modified USPHS criteria and FDI criteria. Investigate the sensitivity of the modified USPHS criteria compared to the FDI criteria in the assessment of the restorations.

Materials and methods Seventy-two restorations (36 Biodentine™, 36 Fuji IX™) were placed randomly in 53 patients. Periapical radiographs were taken at pre-treatment (T0), 12-month (T12), and 24-month (T24) review. Restorations were assessed using the modified USPHS and FDI criteria at T12 and T24.

Results At 24 months, 15 teeth had failed to maintain vitality (6 Biodentine™, 9 Fuji IX™). Clinical success rate of IPC for both materials was 72% and is related to the intensity of reversible pulpitis symptoms. No difference was found between T12 and T24 in the periapical (PA) radiographs and in the integrity of the resin composite restorations overlying Biodentine™ compared to Fuji IX™. There was no difference in the efficacy of the USPHS criteria compared to the FDI criteria in the assessment of the resin composite restorations.

Conclusions Biodentine™ and Fuji IX™ were clinically effective when used as IPC materials in teeth with reversible pulpitis at T24. Resin composite restorations overlying both materials performed well at T24. Using the USPHS or FDI criteria is equally efficient at T24; however, longer term follow-up is needed to establish whether there are sensitivity differences between these assessment criteria.

Clinical significance Teeth with deep carious lesions approaching the pulp and with signs of reversible pulpitis can be treated successfully by indirect pulp capping using either Biodentine™ or Fuji IX™. Using the USPHS or FDI criteria to assess restorations is equally effective at 2 years.

Trial registration NCT02201641

Keywords Indirect pulp capping · Reversible pulpitis · Periapical radiographs · Calcium silicate cements · Glass ionomer cements · USPHS · FDI criteria · MI dentistry · Carisolv gel · Selective caries removal

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Introduction

Dental caries is the most prevalent chronic condition of people worldwide, with individuals being susceptible to this disease throughout their lifetime [1, 2]. The treatment of dental caries has cost implications especially with deep carious lesions approaching the pulp [3, 4]. Reversible pulpal injury resulting from a deep carious lesion can now be treated effectively using a selective, minimally invasive caries removal approach [5]. However, distinguishing between diagnoses of reversible/irreversible pulpitis is fundamental for the treatment to be

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Direct Pulp Capping with Calcium Hydroxide, Mineral Trioxide Aggregate, and Biodentine in Permanent Young Teeth with Caries: A Randomized Clinical Trial

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Abstract

Introduction: Direct pulp capping treatment is intended to preserve pulp vitality, to avoid or retard root canal treatment, and, in cases with an open apex, to allow continued root development. Historically, calcium hydroxide (CH) was the gold standard material, but nowadays calcium silicate materials (CSMs) are displacing CH because of their high bioactivity, biocompatibility, sealing ability, and mechanical properties. However, more randomized clinical trials are needed to confirm the appropriateness of CSMs as replacement materials for CH in direct pulp capping procedures. **Methods:** A randomized clinical trial was conducted that included 169 patients (mean age, 11.3 years) from the Maipo district (Chile). The inclusion criterion was patients with 1 carious permanent tooth with pulpal exposure, a candidate for a direct pulp capping procedure. The patients were randomly allocated to one of the experimental groups (CH, Biodentine, or mineral trioxide aggregate [MTA]). Clinical follow-up examinations were performed at 1 week, 3 months, 6 months, and 1 year. The Fisher exact test was performed. **Results:** At the follow-up examination at 1 week, the patients showed 100% clinical success. At 3 months, there was 1 failure in the CH group. At 6 months, there were 4 new failures (1 in the CH group and 3 in the MTA group). At 1 year, there was another failure in the CH group. There were no statistically significant differences among the experimental groups. **Conclusions:** CSMs appear to be suitable materials to replace CH. Although no significant differences were found among the materials studied, Biodentine and MTA offered some advantages over CH. *(J Endod 2017;■:1–5)*

Key Words

Biodentine, calcium hydroxide, direct pulp capping, mineral trioxide aggregate, randomized clinical trial

Significance

This is the first clinical trial to compare the efficacy of the most frequently used and reported material for direct pulp capping in permanent teeth (CH) versus the new CSMs (MTA and Biodentine).

Treatment of pulpal exposure in permanent teeth is a challenge for clinicians. Traumatic injuries, anatomic anomalies, and extensive caries can cause inflammation of the pulp and arrested root development. Different strategies have been used for vital pulp therapy; these are indirect or direct pulp capping and pulpotomy. The main goal of vital pulp therapy is to preserve pulpal tissue, remove tissue that is contaminated by bacteria, and promote repair of the mineralized tissue barrier (dentin bridge). Direct pulp capping is a procedure wherein a small exposure of pulp is covered with a protective wound dressing (1). This treatment is intended to avoid future root canal treatment or at least postpone it until root formation is complete (2).

Numerous materials have been used throughout the years for pulp capping. Calcium hydroxide (CH) has been the gold standard in recent decades (3–5); however, calcium silicate materials (CSMs) have been used in more and more clinical applications since their development. Calcium hydroxide has some obvious drawbacks, including inflammation and necrosis of the pulp surface after pulp capping, high solubility in oral fluids, degradation over time, the formation of tunnel defects inside the dentin bridge, and low mechanical resistance, which might cause future microfiltration and failure of the treatment (6–9).

Mineral trioxide aggregate (MTA) was the first CSM to be marketed. Since its approval by the Food and Drug Administration in 1998, it has been used with increasing frequency, with very good clinical and *in vitro* results (10–12). In a systematic review with a meta-analysis that compared the effectiveness of MTA and CH as pulp capping materials in permanent human teeth, the conclusion was that MTA has a higher success rate and results in less pulpal inflammation and more predictable formation of a hard dentin bridge than CH (13). This conclusion demonstrates that MTA is a suitable material for direct pulp capping procedures and argues against the continuing recommendation of CH as the gold standard for such treatments. However, as the first CSM, MTA

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Comparative Analysis of 2 Calcium Silicate–based Cements (Biodentine and Mineral Trioxide Aggregate) as Direct Pulp-capping Agent in Young Permanent Molars: A Split Mouth Study

Farbin A. Katge, MDS, and Devendra P. Patil, MDS

Abstract

Introduction: The purpose of this study was to compare Biodentine and mineral trioxide aggregate (MTA) for direct pulp capping in young permanent molars by clinical and radiographic evaluation in 7- to 9-year-old children. **Methods:** In 50 patients, 29 patients with bilateral asymptomatic first permanent molars with carious involvement were selected. According to split mouth design, these patients were then divided into 2 groups, Biodentine group (right side) and MTA group (left side). The pulp-capping procedure was performed by using Biodentine and MTA in 58 asymptomatic bilateral permanent molars with pulp exposure. At each recall (baseline, 6 and 12 months), treatment outcome was assessed clinically through pulpal sensitivity tests as well as radiographically to evaluate dentin bridge formation. **Results:** The study reported 100% success rate with both Biodentine and MTA at baseline and 6- and 12-month follow-up on the basis of clinical and radiographic parameters. These findings were statistically non-significant ($P < .05$) between both groups (Biodentine and MTA). Radiographically, dentin bridge formation was not evident with both groups at baseline, but it was evident after 6- and 12-month follow-up. These findings were statistically non-significant ($P < .05$) in both Biodentine and MTA groups. **Conclusions:** This study reported 100% success rate with both MTA and Biodentine when used as direct pulp-capping agent in first permanent molars in 7- to 9-year-old children. The major limitations of the study were smaller sample size and short follow-up period. *(J Endod 2017;■:1–7)*

Key Words

Biodentine, dentin bridge, direct pulp capping, MTA, permanent molars

Significance

Direct pulp-capping procedure involves the application of a medicament or dressing to the exposed pulp in an attempt to preserve its vitality. MTA and Biodentine act as perfect direct pulp-capping agents in young permanent molars.

The primary objective of pulp therapy is to maintain integrity and health of pulp tissue. It is desirable to maintain pulp vitality whenever possible (1, 2). The healing process of pulp occurs in the form of tertiary dentinogenesis. Vital pulp therapy techniques for permanent teeth are indirect pulp capping, direct pulp capping (DPC), and pulpotomy (3). The rationale behind vital pulp therapy is to maintain the vitality of the dental pulp and to stimulate the remaining pulp to regenerate the pulp-dentin complex (tertiary dentinogenesis). Tertiary dentinogenesis is particularly important in the young permanent tooth with incomplete apical root development (4, 5).

The definition of DPC is "treatment of an exposed vital pulp by sealing the pulpal wound with a dental material placed directly on mechanical or traumatic exposure to facilitate the formation of reparative dentin and maintenance of vital pulp" (3, 6).

In humans, success rate ranges from 30% to 85% in 2- to 10-year retrospective studies (7–9). The success rate of DPC is high in immature permanent teeth. The immature pulpal tissue after pulp-capping procedure allows a favorable tissue response followed by dentin bridge formation (10).

In 1756, Plaff described the first method of capping exposed pulp by using gold foil. In 1921, Dätwyler performed the first scientific clinical study to compare different capping materials (11). In the literature, various materials have been suggested for DPC such as calcium hydroxide, zinc oxide–eugenol cement, polycarboxylate cement, corticosteroids, inert materials (isobutyl cyanoacrylate and tricalcium phosphate ceramic), bonding agents, and glass ionomer cement. Mineral trioxide aggregate (MTA), Biodentine, stem cells, propolis, novel endodontic cement, Emdogain, and TheraCal are some of the newer materials used for pulp capping (12). Calcium hydroxide is a benchmark medicament for vital pulp therapy (3). Both clinically and histologically it has been found to produce satisfactory results in DPC (2). The presence of tunnels in dentin barrier, extensive dentin formation obliterating the pulp chamber, high solubility in oral fluids, and lack of adhesion and degradation after acid etching are some of the limitations reported with calcium hydroxide (3). Because of these disadvantages of calcium hydroxide, other materials have been proposed for DPC procedure during recent years such as MTA and Biodentine.

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Tomographic Evaluation of Reparative Dentin Formation after Direct Pulp Capping with $Ca(OH)_2$, MTA, Biodentine, and Dentin Bonding System in Human Teeth

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Abstract

Introduction: New materials can increase the efficiency of pulp capping through the formation of a complete reparative dentin bridge with no toxic effects. The present study involved tomographic evaluations of reparative dentin bridge formation after direct pulp capping with calcium hydroxide, mineral trioxide aggregate (MTA), Biodentine (Septodont, Saint Maur des Fossés, France), and Single Bond Universal (3M ESPE, Seefeld, Germany) in human teeth. **Methods:** Forty-four caries-free, intact, human third molars scheduled for extraction were subjected to mechanical pulp exposure and assigned to 1 of 4 experimental groups depending on the pulp capping agent used: calcium hydroxide, MTA, Biodentine, or Single Bond Universal. After 6 weeks, the teeth were extracted and processed for cone-beam computed tomographic imaging and histologic examination. Tomographic data, including the density and volume of formed reparative dentin bridges, were evaluated using a scoring system. **Results:** The reparative dentin formed in the calcium hydroxide, MTA, and Biodentine groups was significantly superior to that formed in the Single Bond Universal group in terms of thickness and volume. The dentin bridges in the Biodentine group showed the highest average and maximum volumes. The mean density of dentin bridges was the highest in the MTA group and the lowest in the Single Bond Universal group. **Conclusions:** The volume of reparative dentin bridges formed after direct pulp capping is dependent on the material used. Biodentine and MTA resulted in the formation of bridges with a significantly higher average volume compared with Single Bond Universal, and cone-beam computed tomographic imaging allowed for the identification of the location of dentin bridges. *(J Endod 2015;■:1–7)*

Key Words

Biodentine, calcium hydroxide, cone-beam computed tomographic imaging, direct pulp capping, mineral trioxide aggregate, Single Bond Universal

The most visible reparative response to pulp exposure is the deposition of reparative dentin that provides odontoblasts and other pulp cells and protection against harmful stimuli (1, 2). Reparative dentin formation can be affected by the pulp capping material, the degree of mechanical injury, and inflammatory and bacterial leakage (3). Currently, none of the commercially available direct pulp capping materials fulfills all the requirements of dentists despite rapid progress in the field (4–7). Calcium hydroxide ($Ca[OH]_2$) remains the gold standard for the management of pulp exposure because of its potent antibacterial properties and its ability to stimulate reparative dentin formation and, consequently, pulp healing (2, 6, 8, 9). However, $Ca(OH)_2$ is reported to dissolve over time, and dentin bridges adjacent to the material may contain multiple tunnel defects that open into the underlying pulp (5, 10–14).

Recent studies showed that other materials and strategies may increase the efficiency of pulp capping through the formation of a complete reparative dentin bridge with no chemical toxic effects, thus providing better results than those provided by $Ca(OH)_2$ (12–15). Mineral trioxide aggregate (MTA) is characterized by improved sealing properties and a greater ability to stimulate reparative dentin formation compared with $Ca(OH)_2$; however, it has the disadvantages of difficult handling and application, a longer binding duration, and a relatively high cost (4, 5, 8, 12–14). Several attempts to improve the binding reaction of MTA by the addition of various accelerators and modifiers have been made to provide novel materials that can be effectively used for direct pulp capping (4, 13). Biodentine (Septodont, Saint Maur des Fossés, France) is a new material based on calcium silicates and has properties similar to those of $Ca(OH)_2$ and MTA; furthermore, it overcomes some limitations of the latter 2 preparations (14–16). Previous *in vitro* and *in vivo* studies confirmed that Biodentine has a positive effect on pulp cells and promotes reparative dentin formation in a manner similar to MTA (14–19).

In recent years, dentin bonding systems have also been investigated (5–7, 20, 21) as potential direct pulp capping materials because of their superior adhesion to demineralized dentin tissues. Single Bond Universal (3M ESPE, Seefeld, Germany) represents the next generation of bonding systems available to dentists, the so-called universal systems (7, 22). Application of this material on the dentin surface results in the formation of a hybrid layer, with superior chemical bonding of the monomer

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Pulpal Responses to Direct Capping with Betamethasone/Gentamicin Cream and Mineral Trioxide Aggregate: Histologic and Micro–Computed Tomography Assessments

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Abstract

Introduction: This clinical trial was conducted to evaluate the response of human dental pulp to direct capping with betamethasone/gentamicin (BG) cream and mineral trioxide aggregate (MTA). We hypothesized that the results of direct pulp capping with a topical BG combination would be similar to or better than those with MTA. **Methods:** Thirty-six human first premolar teeth scheduled for orthodontic extraction were randomly divided into 4 groups: BG1 group (n = 9), BG cream with 2-week follow-up; BG2 group (n = 10), BG cream with 8-week follow-up; MTA1 group (n = 8), MTA with 2-week follow-up; and MTA2 group (n = 9), MTA with 8-week follow-up. Teeth were extracted and evaluated at respective time intervals. Micro–computed tomography scanning and histologic analyses were performed for all specimens. Pulp pathology (inflammation, pulp abscesses, and pulp necrosis) and reparative reaction (formation of dentin bridges) were recorded. **Results:** Both BG cream and MTA resulted in significantly better pulpal responses at 8 weeks than at 2 weeks. Dentin bridge formation was significantly thicker in the MTA group at 8 weeks than in any other group ($P < .05$). Inflammation was of the acute type in all groups; no statistically significant differences in the distribution of inflammatory cells were found among the groups. Pulpal abscesses and/or necrosis were observed more often in teeth capped with BG than with MTA. **Conclusions:** Direct pulp capping with both BG cream and MTA was associated with dentin bridge formation. MTA resulted in a significantly better pulpal response, with less inflammation and a thicker dentin bridge at 8 weeks. (*J Endod 2015;■:1–6*)

Key Words

Betamethasone/gentamicin cream, clinical trial, dentin bridge, direct pulp capping, mineral trioxide aggregate

Direct pulp capping is performed to protect pulp affected by caries, trauma, or other injuries to maintain its functional and biological activities (1). Vital pulp tissue is responsible for the formation of secondary dentin, reparative dentin, and peritubular dentin in response to different stimuli (2). In direct pulp capping, a protective layer of biomaterial is placed over the exposed pulp tissue. These biomaterials should be biocompatible and bioactive, and they should possess apatite-forming ability and provide a biological seal (3).

Calcium hydroxide has been a material of choice for pulp capping since 1930 because of its antibacterial activity, ability to release calcium and hydroxyl ions, and low potential for irritation of the traumatized pulp tissue (4, 5). However, it has major disadvantages including high solubility, dissolution in tissue fluids, and poor sealing ability (3, 4).

Calcium silicate–based materials such as mineral trioxide aggregate (MTA) have attained growing attention because compared with calcium hydroxide, they cause less pulp inflammation and form dentin bridges with significantly greater frequency and thickness (6, 7). Although clinical studies have also demonstrated that MTA results in good outcomes when used as an indirect or direct pulp-capping material (8, 9), it has a delayed setting time, poor handling characteristics, and an off-white color (1).

Pulpal trauma or exposure in conjunction with a pulp-capping procedure can induce inflammation in the pulpal tissue. Pulp-capping materials containing anti-inflammatory ingredients may prevent progression to irreversible pulpitis, thus protecting the vitality of the pulp. Topical corticosteroids such as betamethasone have known anti-inflammatory and vasoconstrictive properties (10). Direct application of corticosteroids reduces pulpal inflammation, and betamethasone has demonstrated better anti-inflammatory effects compared with hydrocortisone (11). After betamethasone was applied topically to the dentin of rat molars, the vascular phase of pulpal inflammation was shortened (12). Furthermore, the combination of betamethasone and gentamicin, an antibiotic, has beneficial antimicrobial and anti-inflammatory effects on soft tissues (13, 14). In a direct pulp-capping study in a rabbit model, the topical application of betamethasone and gentamicin cream significantly reduced histopathologic changes in dental pulps compared with those treated with calcium hydroxide (15). However, calcium hydroxide used in this study was hard-setting cement form that might have different pulpal response compared with other forms of calcium hydroxide.

The purpose of this study was to evaluate the response of human dental pulp to direct capping with betamethasone/gentamicin (BG) cream and MTA. We hypothesized that the results of direct pulp capping with a topical BG combination would be similar to or better than those with MTA.

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Partial Pulpotomy in Mature Permanent Teeth with Clinical Signs Indicative of Irreversible Pulpitis: A Randomized Clinical Trial

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Abstract

Introduction: This study aimed to assess the outcome of partial pulpotomy using mineral trioxide aggregate (MTA) compared with calcium hydroxide (CH) in mature cariously exposed permanent molars. **Methods:** Fifty permanent molar teeth with carious exposures in 50 patients >20 years old were included. Preoperative pulpal and periapical diagnosis was established based on a history of presenting pain, results of cold testing, and radiographic findings. After informed consent, the tooth was anesthetized, isolated via a dental dam, and disinfected with 5% sodium hypochlorite before caries excavation. Partial pulpotomy was performed by amputating 2 mm of the exposed pulp, hemostasis was achieved, and the tooth was randomly assigned for the placement of either white MTA (White ProRoot; Dentsply, Tulsa, OK) or CH (Dycal; Dentsply Caulk, Milford, DE) as the pulpotomy agent. Postoperative periapical radiographs were taken after placement of the permanent restoration. Clinical and radiographic evaluation was completed after 6 months and 1 and 2 years postoperatively. Statistical analysis was performed using the Fisher exact test. **Results:** Clinical signs and symptoms suggestive of irreversible pulpitis were established in all teeth. Immediate failure occurred in 4 teeth. At 1 year, MTA showed a higher tendency toward success compared with the CH group, and the difference was statistically significant after 2 years (83% vs 55%, $P = .052$ at 1 year; 85% vs 43%, $P = .006$ at 2 years). Sex did not have a statistically significant effect on the outcome. **Conclusions:** MTA partial pulpotomy sustained a good success rate over the 2-year follow-up in mature permanent teeth clinically diagnosed with irreversible pulpitis. More than half of the CH cases failed within 2 years. (*J Endod 2017;■:1–5*)

Key Words

Calcium hydroxide, deep caries, mineral trioxide aggregate, partial pulpotomy, pulpitis

Significance

Clinical evaluation of vital pulp therapy procedures using biocompatible capping materials is essential for evidence-based clinical practice, particularly in the era of improved understanding of the healing process and regeneration of the dental pulp.

The major goal of all restorative procedures is to maintain the viability of the dental pulp whenever possible, and over the last few decades minimally invasive techniques including partial and full pulpotomy have received wider acceptance in teeth with carious exposure (1, 2). Partial pulpotomy involves the removal of 2–3 mm from the inflamed coronal pulp beneath the exposure followed by placement of a suitable agent over the remaining coronal pulp and a restoration that provides a hermetic seal (3).

Traditionally, symptoms have been widely accepted as indicators of the inflammatory status of the pulp. The presence of relatively mild symptoms relates to reversible pulpitis, whereas carious pulp exposure and more severe symptoms are associated with irreversible pulpitis in which the pulp condition has little chance to revert to normal after the removal of the irritants, and, therefore, root canal therapy is indicated (4).

Several studies have shown that cariously exposed pulps of mature teeth are capable of regeneration, and vital pulp therapy (VPT) need not be restricted to young or asymptomatic teeth (5–8). Furthermore, the presence of spontaneous or severe preoperative pain does not always indicate that the pulp is not capable of repair (9–11), and deep carious lesions are not unconditionally related to an irreversible pattern of pulpal pathology (12). However, partial or full pulpotomy is indicated in such cases rather than simply capping the exposed pulp (13), and the ability to control bleeding after amputation has been suggested as the critical point in terms of the expected outcome (5).

Historically, calcium hydroxide (CH) was the most popular material for VPT; however, American Academy of Pediatric Dentistry guidelines and several authors suggested MTA as a more favorable option than CH (14, 15). It is resistant to dissolution with adequate structural integrity and induces a more homogenous, more localized, and thicker dentin bridge than CH (16, 17). Only 2 studies of CH partial pulpotomy in young permanent teeth have included teeth with a history of spontaneous pain and have reported success rates over 90% (18, 19). The aim of this study was to explore the outcome of partial pulpotomy in mature teeth clinically diagnosed with irreversible pulpitis using MTA compared with CH and monitored clinically and radiographically up to 2 years.

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A randomized controlled trial of various MTA materials for partial pulpotomy in permanent teeth

A randomized controlled trial of ProRoot MTA, OrthoMTA and RetroMTA for partial pulpotomy in permanent teeth

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Running Title: New MTAs for partial pulpotomy in permanent teeth

Human Pulp Responses to Partial Pulpotomy Treatment with TheraCal as Compared with Biodentine and ProRoot MTA: A Clinical Trial

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Abstract

Introduction: Questions exist regarding the efficacy of resin-containing materials such as TheraCal directly applied on the pulp. This study sought to investigate the clinical efficacy of TheraCal as compared with Biodentine and ProRoot mineral trioxide aggregate (MTA) for partial pulpotomy. **Methods:** In this clinical trial, partial pulpotomy was performed for 27 sound human maxillary and mandibular third molars scheduled for extraction. The teeth were randomly divided into 3 groups (n = 9) and underwent partial pulpotomy with TheraCal, Biodentine, and ProRoot MTA. The teeth were then restored with glass ionomer cement. Clinical and electric pulp tests were performed after 1 and 8 weeks. The teeth were radiographed and extracted at 8 weeks. Histologic sections were prepared and analyzed for pulp inflammation and dentinal bridge formation. Data were analyzed by using one-way analysis of variance. **Results:** Clinical examination showed no sensitivity to heat, cold, or palpation in ProRoot MTA and Biodentine groups. Two patients in TheraCal group (20%) reported significant pain at 1 week. Periapical radiographs showed no periapical pathology, and electric pulp test revealed a normal pulp response with no hypersensitivity. Inflammation was absent with all materials at 8 weeks. Normal pulp organization was seen in 33.33% of the teeth in ProRoot MTA, 11.11% in TheraCal, and 66.67% in Biodentine group (P = .06). Biodentine group showed complete dentinal bridge formation in all teeth, whereas this rate was 11% and 56% in TheraCal and ProRoot MTA groups, respectively (P = .001). **Conclusions:** Overall, Biodentine and MTA performed better than TheraCal when used as partial pulpotomy agent and presented the best clinical outcomes. *(J Endod 2017;■:1–6)*

Key Words

Biodentine, partial pulpotomy, ProRoot MTA, TheraCal

Significance

Preservation of pulp vitality is a challenge in immature permanent teeth. Questions exist regarding the efficacy of resin-containing materials. This comparative study between Biodentine, TheraCal, and ProRoot MTA aims to provide a better insight into it. Overall, Biodentine and MTA performed better than TheraCal when used as partial pulpotomy agent and presented the best clinical outcomes.

Preserving pulp vitality after carious or traumatic injuries remains a challenge in immature permanent teeth because this vitality is important for complete root formation (1–3). To this end, vital pulp therapy should be considered in teeth with reversible injury.

ProRoot mineral trioxide aggregate (MTA) is mainly composed of tricalcium silicate, dicalcium silicate, tricalcium aluminate, tetracalcium aluminoferrite, and bismuth oxide (4). When applied directly onto the pulp, MTA as a bioactive material with high sealing ability (3, 5–10) stimulates the formation of dentinal bridge (1, 5–8) and leads to pulp healing, yielding high clinical success rate (6–9). However, MTA has a long setting time (11) and poor handling properties (12) and may lead to tooth discoloration (10, 11).

Biodentine is a tricalcium silicate–based restorative cement used for direct and indirect pulp capping. It has mechanical properties comparable to those of dentin and can be used as a dentin substitute in both the crown and root (3, 13–18). Biodentine is bioactive and nontoxic as tested on human pulp cells (1) and provides marginal sealing by adhering to both dentin and enamel (15, 16). When applied directly onto the pulp in entire tooth cultures, it induced mineralization within the pulp (1) and complete dentinal bridge formation after 6 weeks in human teeth (19). In addition, clinical trials have reported a high clinical success rate of pulpotomy with Biodentine comparable to that of ProRoot MTA (20). Clinical case reports have demonstrated a dentin bridge barrier formation when Biodentine was applied in partial pulpotomy of fractured mature teeth (21).

TheraCal is a new light-cured, resin-modified, calcium silicate–filled base/liner material designed for direct and indirect pulp capping (22). It contains 45 wt% mineral

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Randomized control trial comparing calcium hydroxide and mineral trioxide aggregate for partial pulpotomies in cariously exposed pulps of permanent molars

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Abstract

Chailertvanitkul P, Paphangkorakit J, Sooksantisakoonchai N, Pumas N, Pairojamornyoot W, Leela-apiradee N, Abbott PV. Randomized control trial comparing calcium hydroxide and mineral trioxide aggregate for partial pulpotomies in cariously exposed pulps of permanent molars. *International Endodontic Journal*, **47**, 835–842, 2014.

Aim To compare the treatment outcomes when calcium hydroxide and mineral trioxide aggregate are used for partial pulpotomy in cariously exposed young permanent molars in a randomized control trial.

Methodology Eighty-four teeth in 80 volunteers (aged 7–10 years) with reversible pulpitis and carious pulp exposures were randomly divided into two groups. Exposed pulps were severed using high-speed round burs until fresh pulp was seen. Cavities were irrigated with 2.5% sodium hypochlorite, and the pulp exposures were photographed and measured. Dycal or ProRoot MTA was placed on the pulp. Vitremer was placed over the material until the remaining cavity was 2 mm deep; amalgam was then placed. Teeth were evaluated for clinical symptoms and radiographic periapical changes after 24 h, 3 months, 6 months, 1 year and 2 years. Mean survival times and incidence of extraction were calculated using exact binomial confidence intervals.

Results The median survival time for both ProRoot MTA and Dycal groups was 24 months. Three teeth had unfavourable outcomes with the incidence rate of 0.20/100 tooth-months with ProRoot MTA (95% CI: 0.02–0.71) and 0.11/100 tooth-months with Dycal (95% CI: 0.001–0.60). The incidence of unfavourable outcomes was 0.05/100 (95% CI: 0.001–0.30) and 2.38/100 (95% CI: 0.29–8.34) tooth-months in teeth with small (<5 mm^2) and large (>5 mm^2) pulp exposure areas, respectively.

Conclusions Partial pulpotomy in teeth of young patients with reversible pulpitis, either using ProRoot MTA or Dycal, resulted in favourable treatment outcomes for up to 2 years. The incidence of unfavourable outcomes tended to be higher in teeth with pulp exposure areas larger than 5 mm^2.

Keywords: calcium hydroxide, mineral trioxide aggregate, pulp exposure, pulpotomy.

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Introduction

Partial pulpotomy is generally regarded as the treatment of choice for immature teeth with exposed pulp tissue. This treatment preserves pulp function, thus allowing continued root development (Webber 1984). Cvek (1978) reported that 96% of teeth healed after being treated with partial pulpotomies associated with complicated crown fractures. This technique consists of the surgical amputation of 2–3 mm of inflamed coronal pulp tissue. The wound surface is treated with a capping agent to promote healing and maintain viability of the remaining pulp tissue. It has been suggested that partial pulpotomy, compared

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