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Preventive endodontics – an argument for avoiding root canal treatment

Key words  deep caries lesion, endodontic treatment, IPT, pulp vitality preservation

The success rate of endodontic treatment is lower than expected, and is both time-consuming and expensive. Thus, techniques to enable a clinician to avoid it deserve more attention. Indirect pulp treatment (IPT) is a simple and effective treatment to preserve pulp vitality in teeth with deep carious lesions. Scientific data supports this treatment as means to preserving a healthy, vital pulp.

Introduction

Apical periodontitis (AP) is defined as an oral inflammatory disease caused by a reaction of the host immune system to the presence of microorganisms (planktonic state or biofilm) or their products, which are close to or in the root canal system or at the outside around the root apex. The goal of a root canal treatment is to prevent or heal AP. A biofilm can be defined as microbial aggregates that accumulate at a solid-liquid interface and are encased in a matrix of highly hydrated extracellular polymeric substances (EPS). The anatomy of the root canal system is complex, containing isthmuses, oval extensions and lateral canals, which cannot be reached by root canal instruments. Furthermore, the tooth and root structure consist of dentine, which is a porous material containing tubules with a typical diameter of 0.6–3.2 µm and length of 1–2 mm and which are accessible for microorganisms. Therefore, during root canal treatment, it is not possible to totally eradicate the biofilm. For this reason, it may be difficult to achieve complete healing of AP, although this is the aim. The European Society of Endodontontology (ESE) states: “Following successful root canal treatment the contours of the periodontal ligament space around the root should radiographically be normal.” It should be remembered, however, that periapical radiographs underestimate the incidence of AP, with a false negative value of around 40%.

Since elimination of AP is difficult, it is logical to try to prevent it. One way of achieving this when irreversible pulpal damage is suspected is to carry out a vital pulpectomy, where success rates are high.

In these studies, the absence of AP is assessed using radiographs and the periapical index (PAI). This index (based on the original study by Brynolf in 1967) links radiographic appearances and histological findings; a higher score is related to more inflammatory tissue. Scores 1 and 2 are usually combined to represent the healing or success group. Success rates of endodontic treatment, of both AP and vital cases, are influenced by the decision of the researcher to include or exclude PAI score 2 in the healing/success group. If PAI score 2 is removed from the healing group and only PAI score 1 represents absence of inflammation and normal radiographic appearance (ESE 2006), the success rates of endodontic treatment drop from 94% to 70% in vital cases.
Unfortunately, animal studies with histological assessment suggest that vital pulpectomy may be less successful than expected\textsuperscript{12-14}. AP was present in a high percentage of teeth up to 12 months after performing vital pulpectomy. This is confirmed by a recent \textit{in vivo} evaluation of endodontic treatment performed in teeth clinically diagnosed with irreversible pulpitis\textsuperscript{15}. Using CBCT for radiographic analysis, 13.7\% of the teeth showed a periapical radiolucency after a 1 year recall. Root canal treatment is time-consuming and expensive. It weakens the tooth, possibly resulting in vertical root fractures and apical cracks, both of which may reduce the survival of teeth\textsuperscript{16,17}. For these reasons root canal treatment should be avoided when possible. One way to achieve this may be to use the technique of indirect pulp treatment (IPT) rather than fully excavate deep carious lesions, leading to unnecessary exposures. IPT is a procedure performed in a tooth with a deep carious lesion approximating the pulp, but without the signs or symptoms of pulp degeneration\textsuperscript{18}. The caries surrounding the pulp is left in place to avoid pulp exposure and is covered with a biocompatible material\textsuperscript{19}. Therefore, in IPT only the biofilm covering the dentine surface in the cavity can be removed rather than all ‘infected dentine’\textsuperscript{20}. To support the rationale for IPT, we now give an overview of caries and its control, updating an earlier published article\textsuperscript{35}.

\textbf{What is caries?}

Dental caries has a dynamic process. It is a chemical dissolution brought about by metabolic activity in a microbial deposit (biofilm) covering a tooth surface at any given time. Over time, the outcome of these fluctuations may result in a disturbance of the equilibrium between the tooth mineral and the surroundings. Mineral loss, subsequent lesion formation and possibly cavity formation in teeth, is a symptom of imbalance in this dynamic process. The metabolism in the biofilm is a ubiquitous, natural process, part of having teeth. However, its possible consequence, lesion formation and progression can be controlled so that a clinically visible lesion never forms or an established lesion arrests\textsuperscript{21}. Wherever a patient can access and disturb the biofilm with a fluoride-containing dentifrice, a filling is not needed. This simple cleaning measure will control caries lesion progression.

In one case example of caries management, a girl of 7 years was referred because of dental fear (Figs 1a to 1h). Oral and radiographical examination showed aside from two cavities in primary molars, three deep occlusal cavities in hypomineralised first permanent molars (teeth 16, 26 and 46) and one medium deep cavity (tooth 36). The clinical diagnosis for these teeth was reversible pulpitis and IPT was performed. The cavities were filled with a high filled glass ionomer (Ketac Molar; 3M ESPE, St. Paul, MN, USA). After 3 years, the molars showed no clinical and/or radiographical symptoms. After 4 years, all molars showed a normal reaction to the cold test.

\textbf{When is a filling needed to control caries?}

A cavitated lesion, where the patient cannot access the biofilm with a toothbrush, is likely to progress and require restoration as part of caries lesion control\textsuperscript{22}. Put simply, the filling restores the integrity of the tooth surface and allows the patient to clean the teeth again. Thus, from a cariological point of view, restoring the tooth is part of plaque control. Fillings are required in the following circumstances:

- Cavitated occlusal lesions, detected by a clinical-visual examination of clean, dry teeth; these lesions are usually visible in dentine on a bitewing radiograph\textsuperscript{23,24}.
- Cavitated approximal lesions; these are clearly shown in dentine on a bitewing radiograph but it should be noted that cavitation cannot be diagnosed from the radiographic examination\textsuperscript{22}.

One such case when a filling was required for the control of caries is described as follows. A girl of 8 years was referred because of non-cooperative behaviour (Figs 2a to 2c). In the mandibular hypomineralised first mandibular right permanent molar, a deep caries lesion was observed. The clinical pulpal diagnosis was reversible pulpitis. The clinically leaking restoration was removed. IPT was performed and the cavity filled with a high-density glass ionomer (Ketac Molar, 3M ESPE). After 2 years, the immature molar was completely matured, symptom-free and without signs of apical pathology on the radiograph.
Fig 1  (a) Deep carious lesions in teeth 16 and 46 in 2003. (b) Very deep caries lesion in tooth 26 the same year. (c) Panoramic exam half a year after treatment. (d) Panoramic exam 3 years after treatment (2006). (e) Radiograph of tooth 26, 3 years after treatment (2006). (f to h) Clinical performance of teeth 16, 26 and 46 respectively (2007).

Fig 2  (a) Bitewing: deep caries and leaking filling in tooth 46. (b) Radiograph showing immature roots. (c) Radiograph 2 years after IPT: the immature molar was completely matured and showed no clinical symptoms and/or radiographical signs of apical periodontitis.
Objectives of restoration from a carioloical point of view

Caries removal and restoration should:
- arrest caries lesion progression
- provide an adequate base for the restorative material
- produce a filling that the patient can clean.

The advent of adhesive restorative materials was particularly exciting, because whereas amalgam could be regarded as a plug in a hole, bonded adhesive materials might be capable of improving cavity seal and even giving back some strength to tooth tissue undermined by demineralisation. Good cavity seal is thought to be of great import, because it is leakage of bacteria that potentially damages a vital pulp. Supporting tooth tissue undermined by demineralisation with adhesive materials, may allow preparations to be much more conservative.

An old argument on caries removal

Discussions on how much demineralised tissue must be removed before restoration are hardly new. John Tomes and GV Black were arguing the toss about this issue some 150 years ago:

“It is better that a layer of discoloured dentine should be allowed to remain for the protection of the pulp rather than run the risk of sacrificing the tooth”.

“It will often be a question of whether or not the pulp will be exposed when all decayed dentine overlaying it is removed. It is better to expose the pulp of a tooth than to leave it covered only with softened dentine.”

This article now focuses on the biologic arguments for and against vigorous caries removal before examining the research evidence on the consequences of incomplete caries removal.

Pulpo–dentinal reactions to dental caries

Dentine is a vital, cellular tissue, containing the cellular processes of the odontoblasts. Thus dentine and pulp must be considered together. The ecological catastrophe in the biofilm, which is the caries disease process, is an assault on this vital tissue that is capable of defending itself. In 1967, Massler distilled current scientific knowledge on this matter, including describing his own research performed over a period of 11 years on more than 800 human teeth. His sense of frustration at some of his colleagues jumps from the page:

“It is somewhat disturbing to the biologically orientated clinical teacher to witness the overly focused attention of some dentists upon the operative and restorative phases of dentistry, the ‘drilling and filling’ of teeth, to the neglect of the disease process which caused the lesion (cariology) and the pre-operative treatment of the wounded tooth–bone.”

A combination of defence and degenerative reactions characterizes the caries lesion in the pulpo–dentinal complex. Massler’s particular contribution was to point out how essential it is to differentiate active from arrested lesions if one is to make any sense of the biologic reactions. From this, a logical management follows. This seeks to convert an active lesion into an inactive or arrested lesion, thus aiding the defence and healing processes in dentine and pulp before restorative procedures are attempted.

Massler showed that under an active lesion, the dentinal tubules were permeable, whereas under arrested lesions, there were sclerotic zones in the dentine that were impermeable to dyes and isotopes. He pointed out that the plugging of the tubules forms a very effective barrier against the further penetration of toxic materials toward the pulp. Thus it would be biologically crazy to damage this area by attacking it with a bur. Massler described an active lesion as one characterised by an active bacterial colony on the surface (the infected layer) and a very wide layer of demineralised dentine beneath, containing few pathogenic microorganisms (the affected dentine). He subsequently pointed out that most lesions found clinically were a combination of active and arrested lesions. At the periphery of the lesion, an active lesion is often spreading under the overhanging enamel, along the dentinoenamel junction, while the central, more easily cleaned area is hard and partially remineralised (Fig 3). Thus, as stated at the beginning of this article, the lesion reflects the activity in the overlying biofilm.
Furthermore, the pulpo-dentinal complex reacts with the formation of tertiary dentine, which is protective because it reduces diffusion towards the pulp, replacing dead odontoblasts and releasing growth factors encapsulated in dentine, due to softening of the dentine. All these processes will promote pulp healing. Beneath deep carious lesions, the pulp presents chronic inflammatory exudates, including lymphocytes, macrophages, and plasma cells. However, an inflammatory reaction does not mean that the pulp is irreversibly damaged; inflammation is a normal healing response of the pulp (and other tissues) to a stimulus. Because healing is a longitudinal process depending on the virulence of the microorganisms present and the healing capacity of the pulp, it can be difficult to predict the outcome for the pulp in a deep lesion. For instance, it is now thought that deep exposed carious lesions are not automatically associated with irreversible pulpitis. However, the clinician cannot make this histological diagnosis and uses a clinical rule of thumb, reversible or irreversible pulpitis, which is a clinical diagnosis based on the presenting symptoms. The clinical diagnosis will be discussed later.

Can and should infected dentine be removed?

If the biofilm at the tooth surface drives the caries lesion, logically all that must be removed to arrest the lesion is the biofilm. Supposing a clinician disagrees with this interpretation and wishes to remove all the infected dentine, can this be achieved? The answer to this question is that it is not possible. Shovelton’s review of 1968 showed that softening of dentine generally precedes the organisms responsible for it, but a few organisms will remain even if all the soft dentine is removed.

Consider next this case of deep caries in a child with congenital heart disease (Figs 4a to 4d). At the first visit, a bitewing radiograph of a boy 12 years of age, who was medically compromised by congenital heart disease, showed a deep caries mesial lesion in tooth 26. Unfortunately the treatment was performed almost 8 months later because of several circumstances. IPT was performed and the molar was restored with glass ionomer (Ketac Molar, 3M ESPE). Three years after treatment, the glass ionomer restoration was partly removed. The glass ionomer part covering the deepest part of the cavity was left in place. Next, the tooth was filled with dental composite. No clinical symptoms and/or apical pathosis on the radiograph were detected.

Conventional caries removal

The most commonly used criterion for the removal of infected dentine is to scoop out all the soft matter with an excavator. At the dentinoenamel junction, some schools teach that the area should be made stain-free as well as hard; others just stay hard and ignore the stain. Because staining is an unreliable guide to the level of infection in the dentine, and because a few bacteria will remain whatever
Over the pulpal surface, stained dentine should remain so long as it is reasonably hard. Provided a tooth is symptomless and responds as being vital to pulp testing, vigorous excavation over the pulpal surface seems positively contraindicated once the cavity floor is reasonably firm. The student, however, will find that teachers do not agree on what constitutes reasonably firm. Table 1 provides an overview of the caries removal techniques used in different studies.

The subjectivity of these assessments led to the development by Fusayama of red dyes to be used clinically to differentiate infected from affected dentine. Infected dentine was shown to be an irreversibly damaged layer, while affected dentine was the inner, remineralisable zone. The same author tentatively suggested the dye staining front coincided with the bacterial invasion front. Thus, in theory, this dye could be used to identify the carious tissue that is infected with bacteria and thus needs to be excavated. Subsequently, several studies showed the dye does not necessarily discriminate infected tissue and use of the dye could lead to over preparation of cavities, encouraging removal of excess tissue at the dentinoenamel junction and removal of sclerotic and reparative dentine over the pulpal surface. For these reasons we would not advocate the use of caries dyes.

The evidence base for ultraconservative caries removal

Thus far, this article has questioned the biologic basis for contemporary caries removal, which seeks to remove most infected demineralised dentine. Is this appropriate with the present knowledge about the disease and the way in which lesions progress?
What would happen if most of the infected dentine was left and a restoration placed? Would the caries process arrest? The following groups of studies give some information about this.

### Studies placing fissure sealants over carious dentine

When fissure sealants were placed over carious dentine, sealed lesions appeared to arrest clinically and radiographically, whereas lesions progressed if sealants were lost or in unsealed control teeth. There was no pain in sealed teeth and if they were re-entered for microbiological sampling, microorganisms were eliminated or decreased with time.

### Stepwise excavation studies

In stepwise excavation, only part of the soft dentine caries is removed at the first visit during the acute phase of caries progression. The cavity is restored and re-opened after a period of weeks. Further excavation then is performed before a de-
finitive restoration. The objective of the exercise is to arrest lesion progression and allow the formation of reparative dentine, making pulpal exposure less likely in vital teeth with deep carious lesions but no symptoms of irreversible pulpitis.

The procedure has been investigated scientifically for over 30 years. These studies have involved baseline investigation of carious dentine and then a reanalysis after a period of sealing. Collectively these studies reveal much about the consequences of sealing infected dentine in teeth.

Studies have been done in permanent and deciduous teeth, usually with deep lesions. The amount of dentine removed at the first visit varies greatly, from only accessing carious dentine to removing the bulk of the carious dentine. With the Hall technique, no carious dentine at all is removed. The restorative materials are also very variable, including calcium hydroxide, zinc oxide and eugenol, amalgam, glass ionomer cement, and resin composite. Times to re-entry can be as short as 3 weeks or as long as 2 years. Caries lesion activity has been assessed clinically, radiographically, and often by microbiological examination at the original visit and on re-entry. Despite these very different methodologies, clinical success is high, exposure of the pulp usually avoided and there are rarely symptoms between visits. On the other hand, exposure of the pulp is common in controlled, conventionally excavated lesions. The dentine is often altered on re-entry, being dryer, harder, and darker.

Several studies involve microbiological monitoring and, as with fissure sealant studies, these indicate substantial reductions in cultivable flora, although some microorganisms may survive. Intriguingly, several studies suggest the organisms have altered on re-entry to a less cariogenic flora, which is entirely logical, because the supply of nutrients will diminish. Not only are the organisms cut off from the oral environment, they are cut off from nutrients from the pulpal side by tubular sclerosis and reparative dentine. They are in a stressful environment and adapt accordingly. One study even showed the flora on re-entry to be identical in the fully excavated control teeth and the teeth where soft, heavily infected dentine was left. Collectively, these studies seem to put the final nail in the coffin of excavating demineralised dentine because it is infected. The few microorganisms that survive seem to be opportunistic squatters that have adapted to their new environment.

Why re-enter in stepwise excavation?

Stepwise excavation is different from indirect pulp capping, where the dentist attempts to remove as much infected dentine as possible, stopping just before exposure. However, there is no way of knowing the proximity to the pulp and this is a fine and difficult judgment. There is no such concern in stepwise excavation where the dentist is going to re-enter and the final excavation allows the dentist to be sure there is no exposure. It is interesting to note that on re-entry up to 17% of pulps may be exposed by the further instrumentation. Is this justified? It is unlikely to alter the microbiology and one wonders if it is necessary, particularly in deciduous teeth, which will exfoliate. Furthermore, re-entry and deeper excavation will also add iatrogenic trauma to the pulpal tissues.

Placing a final restoration over soft dentine

To many, this will seem like heresy, but Ribero and colleagues concluded that the clinical performance of the restorations in deciduous teeth was not adversely affected by the incomplete caries removal after a year. Two other studies in this group were randomised controlled clinical trials and will be considered in the next section.

Systematic review of randomised controlled clinical trials

A systematic review of randomised clinical trials provides the best evidence on which to base clinical practice. The authors examined 8 clinical trials with a total of 934 participants and 1372 teeth, assessed at 1 year. The comparisons were:

- stepwise caries removal compared to complete one stage of caries removal (4 trials)
- partial caries removal compared to complete caries removal (3 trials)
- no dentinal caries removal compared to complete caries removal (2 trials).
Both deciduous and permanent teeth were included. The evidence was judged as moderate, as there was a risk of bias.

Explanation is required as to what the “no dentinal caries removal” implied. One study on deciduous teeth in general dental practice compared Hall crowns to glass ionomer restorations. Hall crowns involve neither caries removal nor tooth preparation. The crown is simply filled with glass ionomer cement and placed on the tooth with finger pressure or the child’s occlusal force. In the other study there was no caries removal in occlusal lesions in permanent teeth, half way through dentine on radiograph. Access to caries was gained by removing enamel over the soft, wet lesions, leaving a sound, bevelled rim of enamel to bond to. Lesions were restored leaving moist, soft, infected dentine both at the dentinoenamel junction and over the pulp.

The results of these studies showed:
- Stepwise caries removal resulted in a 56% reduction in the incidence of pulp exposure, compared to complete caries removal. In these four studies, the mean incidence of pulpal exposure was 34.7% in the complete caries removal group and 15.4% in the stepwise group following re-entry and further excavation. There was no difference in the outcome of signs of pulpal disease, although to obtain this result the studies had excluded all the exposed teeth, and what subsequently happened to these teeth is unknown.
- Partial caries removal reduced the incidence of pulpal exposure by 77% compared to complete caries removal (29.9% exposures in the complete caries removal groups and 5% in the partial caries removal groups). There was insufficient evidence to determine whether or not there was a difference in signs and symptoms of pulpal disease or restoration failure.
- The ‘no caries removal’ groups were very different studies as explained above. The occlusal caries study gave no indication of signs and symptoms of pulpal disease or restoration failure in the no caries removal group and these teeth were subsequently followed for 10 years with no evidence of failure. The Hall crowns in deciduous teeth showed a statistically significant difference in restoration failure in the control, glass ionomer, restored teeth and 5-year results now confirm this. However, it should be noted that the control material was a glass ionomer cement, which has been shown to have a poor survival rate in approximal cavities.

A recently published randomised controlled trial with a 3-year recall comparing partial caries removal (PCR) and stepwise caries removal (SW) is important. The PCR group were restored with glass ionomer cement and the SW group were initially restored with calcium hydroxide and zinc oxide and eugenol to facilitate re-entry. PCR showed a statistically significant improvement with regard to the maintenance of pulp vitality as compared with SW removal after a 3-year follow-up period. The adjusted survival rates were 91% for the PCR group and 69% for the SW group (P = 0.004). However, this finding appeared to be caused by the temporary restoration (calcium hydroxide and zinc oxide and eugenol) used in the SW group being lost from the cavities when patients failed to attend recall appointments. Cavity seal was lost and patients returned in pain. There is a lesson here; a permanent restoration would have been a wiser choice. When completed SW treatments were compared to PCR treatments, no significant differences were found. From this we can tentatively conclude re-entry may not necessarily be associated with a higher survival rate.

Clinical pulp diagnosis

For a tooth with a deep carious lesion, diagnosis guides the treatment decision and predicts outcomes. When the clinical diagnosis is ‘reversible pulpitis’, the pulp responds as being vital and the inflammation is considered to be to be reversible. These teeth are the ideal candidates for IPT treatment (Figs 5a to 5g). Pulp tests will provoke a short, sharp pain reaction after a temperature stimulus, but the pain will disappear after the temperature stimulus has been removed. There is no spontaneous or continuous pain. Drinking or eating can provoke pain but the pain should disappear after removal of the stimulus. The patient can usually identify the tooth involved. It has been shown that in 95% of cases, percussion did not provoke pain. In contrast, 55% of teeth diagnosed with irreversible pulpitis
were tender to percussion\textsuperscript{87}. Although IPT is probably mostly performed on children or young adults, IPT also works in the older patient, as documented in the case illustrated in Fig 6.

When the clinical diagnosis is ‘irreversible pulpitis’ the pulp, although still responding as vital, is judged to be irretrievably damaged and a (partial) pulpectomy is required\textsuperscript{85}. In this situation a temperature stimulus will provoke a pain reaction, which lingers when the stimulus is removed. It can be difficult to differentiate between a reversible and irreversible pulpitis and the clinical diagnosis is somewhat arbitrary\textsuperscript{86}. It does not reflect the histological status and regeneration potential of the pulp. The extent and duration of the pain, earlier pain complaints, recent treatments, past trauma, deep restorations, and pulpal age should all be taken into consideration when making this clinical diagnosis and subsequent clinical decision.

It would be helpful if research could improve the reliability of the diagnosis because the assumed future viability of the pulp rests upon it (Fig 7). Discussing the diagnosis, including its uncertainties and their consequences, with the patient to involve them in the treatment decision is mandatory as is a careful follow-up. The informed patient who ‘owns’ the decision to be conservative, is a partner in the investigation. They will understand, be forewarned and consent to a diagnosis that may not be correct, they are prepared to ‘take the risk’ and, if pain persists, will realise that pulpectomy is no longer avoidable.

\textbf{Fig 5} (a) Bitewing 3-5-2005: deep carious lesions in teeth 85 (indication IPT) and 84 (indication extraction). (b) Clinical image of tooth 85. (c) The dentinoenamel junction is clean and central: the infected dentine is still present and covered with biomass/biofilm. (d) A prophy brush is used to remove the biomass (2000 rpm limited pressure). (e) Centrally, the infected dentine is still present. (f) Control radiograph after 2 years and 4 months. (g) Clinical situation after 2 years and 4 months.
Based on the evidence – what do we do in the clinic?

There is good research evidence for incomplete caries removal and IPT. The advantages of IPT are that a re-entry (as in stepwise excavation) is not necessary and preservation of pulpal dentine reduces the chance of exposure, possibly facilitating pulpal regeneration. Avoiding pulpectomy reduces treatment time and cost, and preservation of the tooth and root structure may increase the longevity of the tooth.

What material should cover the non-excavated dentine surface?

After removing the biofilm, the remaining dentine will be moist and soft. Which material should be chosen to cover it? Traditionally, calcium hydroxide (Ca(OH)₂) is used because it is alkaline, biocompatible and induces pulp-dentine remineralisation. However, this could dissolve in time, perhaps hampering the seal of the restoration by allowing microbial leakage.

Fig 6  (a) Radiograph: deep caries in tooth 37 (2006). Tooth is sensitive to cold with spontaneous pain. (b) Clinical image: initial stage. (c) Clinical image: after using caries detector. (d) Clinical image: after using the prophy brush before filling. (e) Radiograph directly after treatment. (f) Radiograph 4 years after IPT (2010). Tooth reacts sensible to cold test and is asymptomatic.

Fig 7  Diagram of pulpal diagnosis.
Glass ionomer cements seem to have advantages:

- Biocompatibility comparable to calcium hydroxide after 4 years\(^90,91\).
- No dissolution reported.
- Apparently successful in IPT-investigations and as a sealing material in pulpotomy studies\(^20,92-94\).
- A bio-active material with the potential to remineralise residual carious dentine\(^95\).
- Electron probe microanalysis (EPMA) demonstrated that both fluorine and strontium ions from glass ionomer cement can penetrate the underlying demineralised dentine\(^96\).
- The sealing ability of glass ionomer is good on moist dentine due to its hydrophilic character\(^97-99\).
- Resin-modified glass ionomer cement is compatible with dental bonding agents, preventing microleakage, with strength, solubility and antibacterial activity superior to calcium hydroxide\(^100-104\).

There are other restorative materials on the market, which harden when placed on moist dentine, e.g., mineral trioxide aggregate (MTA) and EndoSequence, a bioceramic material (Brasseler, Tulsa, OK, USA). MTA is biocompatible\(^105\), induces the formation of hydroxyapatite, exhibits good sealing ability\(^106\) promotes the release of cytokines and growth factors that are encapsulated in the dentine\(^107\) and is successfully used for direct pulp capping\(^108\). This could be useful where there are undetectable micro-exposures. Both materials result in a higher pH and have an antimicrobial effect\(^109\).

EndoSequence (Brasseler) is biocompatible but its hardening is questioned\(^109\). Perhaps these materials are preferable to glass ionomer cement but randomised, controlled clinical trials will be required to be sure. It is very possible that the factor of overriding importance is not the material over the pulp, but the cavity seal of the restoration. When calcium hydroxide, glass ionomer cement and wax were used as a negative control to protect demineralised and infected dentine following partial caries removal\(^110\), dentine hardening, reorganisation, and decreased bacterial numbers occurred irrespective of the dentine protection used.

**Treatment protocol**

Based on the above discussions, the authors propose a treatment protocol based on a retrospective clinical study including 120 primary and permanent teeth published in 2010 by Gruythuysen et al\(^20\). The 3-year survival rate was 93% for the permanent teeth and 96% for the primary teeth.

After administering anaesthesia and applying the rubber dam, the cavity is adapted to allow removal of the biofilm from the cavity surface and the placement of an adhesive restoration. Since the seal of the cavity is critical, marginal adaptation of and support for the adhesive restoration is very important. ‘Soft dentine’ is removed from the dentinoenamel junction with round burs in a slow speed handpiece with water-cooling until the dentine forms a sound basis (hard to probe). The biofilm (biomass) is removed from the dentine surface with a prophy brush, coated with fluoride toothpaste, and used at slow speed (Screw-type black Crescent; Dentsply Rinn, Elgin, IL, USA; 2000 rpm). A glass ionomer or MTA lining is placed on the dentine surface and finally a definitive adhesive restoration can be placed.

**What do we still not know?**

**Topics for further research**

The following seem worthy of further study:

- A repeat of the Maltz study\(^84\) comparing PCR and SW excavation using the same restorative materials in both PCR and SW groups to further investigate the need to re-enter.
- The longevity of restorations placed on soft dentine. There is a theoretical problem of restorations placed on ‘soggy bottoms’ failing. However the work must be done *in vivo* where the soft, wet dentine changes following the initial sealing (it becomes harder, darker and dryer) and the microorganisms change to a less cariogenic flora. These changes are bound to be relevant to the outcome. It is irrelevant to investigate these matters in the laboratory where the biological responses of dentine sclerosis and tertiary dentine formation are absent.
- Which material should be chosen to cover the soft dentine?
• A recently published case report showed healing of AP associated with a tooth with the clinical diagnosis of irreversible pulpitis after an IPT treatment111. Regarding the effectiveness of IPT in the management of irreversible pulpitis: does this ever work when the clinical diagnosis is irreversible pulpitis? What factors (e.g., patient age) predispose to success or failure?

• Evaluation of radiographic changes before and after treatment including pulpal dimensions, reparative dentine, and apical periodontitis.

Randomised, controlled clinical trials are required, but these are both expensive and time-consuming. We would like to invite dentists to visit our website (www.pulpodentalhealth.com) where they can download protocols to join clinical research.

■ Conclusion

The success rate of endodontic treatment is lower than expected, and it is both time-consuming and expensive. Thus, techniques to avoid it deserve more attention. IPT is a simple and effective treatment that can be used to preserve pulp vitality in teeth with deep carious lesions. Scientific data supports this treatment as a means to preserving a healthy, vital pulp.

■ Postscript

It was interesting that Maltz (2013)84 did not choose a complete caries removal group as a control group. She compared stepwise caries removal and partial caries removal and commented that the evidence would now make complete excavation in a symptomless, vital tooth with a deep lesion unethical. We entirely agree.

■ Cases

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