Preserving pulp vitality: part two – vital pulp therapies

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Key points

- There is sufficient evidence to recommend calcium silicate cements ahead of calcium hydroxide for all vital pulp therapies, but consideration must be given to potential discolouration in material selection.
- The main driver for a decision between different vital pulp therapies is the visual appearance of the pulp and the ability to control haemorrhage.
- Following careful case selection, teeth receiving vital pulp therapies with calcium silicate cements have a good prognosis, equal to pulpectomy and root canal treatment, which still remains an option in the event of failure.

Abstract

Vital pulp therapies (VPTs) aim to preserve the vitality of the pulp. The European Society of Endodontology have begun a campaign to raise awareness on the efficacy of VPTs following on from the publication of their 2019 position statement, aimed at both specialists and general dental practitioners. This review examines the current evidence surrounding VPTs and provides a rational approach to the management of the exposed pulp with the aid of case studies. Success lies in accurate diagnosis and case selection, along with well-executed treatment and appropriate follow-up protocols. The introduction of calcium silicate cements has made these treatments more predictable.

Introduction

Where deep caries management, trauma or iatrogenic damage results in pulp exposure, traditional approaches have advocated complete pulpectomy and root canal treatment (RCT). The aim of vital pulp therapy (VPT) is to assess and manage pulpal inflammation and maintain pulp vitality by preventing the progression of inflammation through to pulpal necrosis, avoiding the need for complex RCT.[1,2] Success rates of VPTs have been reported to be comparable at five years to conventional pulpectomy and RCT,[3] even in teeth with irreversible pulpitis,[4,5] with the advantage of dentine preservation and that the pulp retains its ability to react to future insults and noxious stimuli.

VPT techniques have the potential to be simple and both cost- and time-efficient. If they are unsuccessful, RCT may still remain a viable treatment option in the future. While conventional RCT has excellent outcome survival and success rates, particularly in 'vital' cases,[6] it is not without its technical challenges.[7] We are now in a position to better understand the complexities that conventional RCT possesses, particularly anatomically, with the advent and now wider use of cone beam computerised tomography (CBCT) in endodontology demonstrating the intricacies and challenges of chemo-mechanical disinfection of the root canal anatomy.[8]

This paper builds on the discussion around diagnosis and treatment options for managing deep caries, and will consider the range of VPTs available. Appropriate diagnosis and careful case selection is essential, as are the use of appropriate operative management techniques. A review of pulpal diagnoses was considered in the first paper of this two-part series.

The categorisation of pulpitis as 'reversible' or 'irreversible' remains clinically useful and is almost universally accepted,[9] but a patient's symptoms and clinical appearance may not fit exactly into either category. Furthermore, definitive treatment planning resulting in extraction or conventional endodontics based on pre-operative symptoms alone may be inappropriate. These are very much diagnoses of convenience as it is impossible to determine clinically the histological status of the pulp without removal of the tooth.[10,11]

Newer proposed classifications go some way to removing this diagnostic dichotomy and recognising that the various stages of inflammation are much more of a continuum (Table 1).[11] VPTs work on the assumption that, biologically, the pulp has the capacity to regenerate and repair as long as the insult is removed and the inflammation can be successfully managed. The exposed pulp's ability to heal should be assessed on its appearance, and in particular, the ability to control bleeding.[12] This clinical feature is used as a surrogate marker to determine the severity of pulp inflammation and inform decision-making as to whether to carry out a direct pulp cap (DPC), partial pulpotomy, full pulpotomy or pulpectomy (Table 2).

Operative management

The success of VPTs rely on the ability to control inflammation alongside managing any potential bacterial contamination of the exposed pulp. As with the management of deep caries, rubber dam is mandatory where VPT is being considered.[2] As well as limiting bacterial contamination, this allows adequate

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Table 1 Proposed pulpitis classification[11]

Diagnosis	Likely symptoms	Likely histology	Suggested treatment
Initial pulpitis	Heightened but not lengthened response to cold Not tender to percussion No spontaneous pain	'Healthy pulp' or local inflammation confined to the coronal pulp	Indirect pulp therapy/coronal pulpotomy
Mild pulpitis	Heightened and lengthened response to cold, warmth and sweet stimuli which can last up to 20 seconds Possibly tender to percussion	Local inflammation confined to the coronal pulp	Indirect pulp therapy/coronal pulpotomy
Moderate pulpitis	Clear symptoms Strong, heightened and prolonged reaction to cold which can last for minutes Possibly tender to percussion Possible spontaneous dull pain which can be more or less supressed with pain medication	Extensive local inflammation confined to the coronal pulp	Partial/complete pulpotomy
Severe pulpitis	Severe spontaneous pain Clear pain reaction to cold/hot stimulus Often sharp to dull throbbing pain Sleep affected Tender to percussion	Extensive local inflammation of the coronal pulp which may extend into the root	Direct visualisation of the pulp. If: No prolonged bleeding of radicular pulp stumps: coronal pulpotomy Continued bleeding: superficial pulpotomy with endodontics up to healthy pulp or complete pulpectomy if required

disinfection using sodium hypochlorite as well as enhancing moisture control for definitive restoration.

If effective rubber dam isolation is not immediately possible due to the depth of an interproximal carious lesion, the periphery of the lesion should be cleared to sound tooth structure, staying away from the pulp. The papillae should then be appropriately managed to allow effective rubber dam isolation before proceeding with caries removal centrally, thereby preventing contamination of the pulp.[13] If isolation is still not possible, the decision-making process may favour initial stabilisation of the tooth by ensuring a four-walled cavity, pulp extirpation and RCT. As with all deep caries management, magnification is important for undertaking VPTs, enabling assessment of caries removal and pulpal status with greater accuracy.[14]

Direct pulp cap

Placement of a DPC aims to create an environment which prevents bacterial ingress while also promoting dentine bridge formation and pulp healing, ultimately aiming to preserve pulp vitality.[15,16,17] Bacterial microleakage around restorations has been shown to be an important determinant in pulp inflammation.[18] In the absence of bacteria, the pulp is capable of maintaining vitality and forming a dentine bridge, even in the presence of food debris.[19] A dentine bridge is considered essential to prevent the ingress of bacteria and allow re-establishment of the healthy pulp.[20,21] If pulp tissue were to lose its homeostatic union with dentine, it would eventually undergo localised degeneration, atrophy and shrinkage away from the defect.[22]

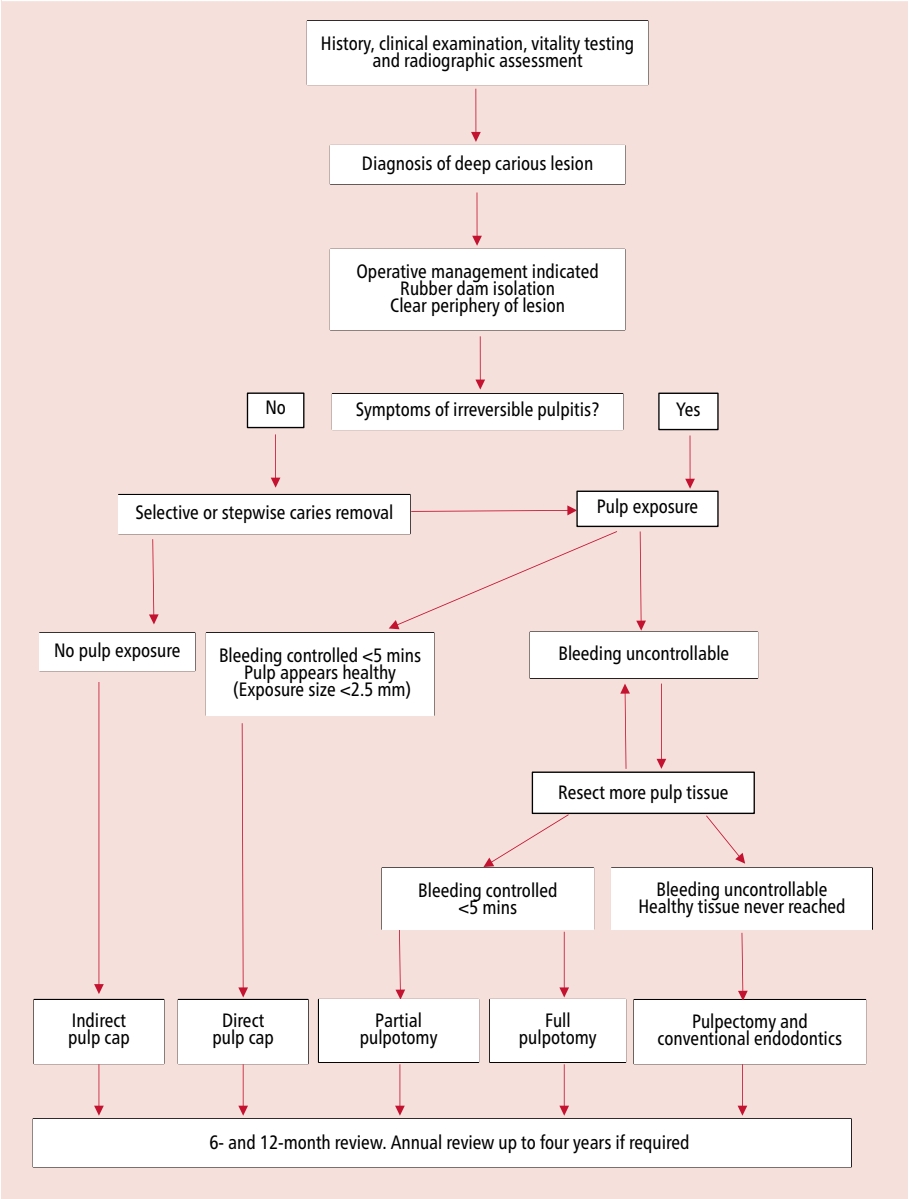
Table 2 Definitions of vital pulp therapies[2]

Vital pulp therapy	Definition
Direct pulp cap	Following the preservation of an aseptic working field, application of a biomaterial directly onto the exposed pulp, before immediate placement of a permanent restoration
Partial pulpotomy	Removal of a small portion of coronal pulp tissue after exposure, followed by application of a biomaterial directly onto the remaining pulp tissue before placement of a permanent restoration
Full pulpotomy	Complete removal of the coronal pulp and application of a biomaterial directly onto the pulp tissue at the level of the root canal orifice(s), before placement of a permanent restoration
Pulpectomy	Total removal of the pulp from the root canal system followed by root canal treatment, before placement of a permanent restoration

It has been discussed that, although the absence of symptoms indicative of irreversible pulpitis is a positive prognostic factor,[2,23] other factors may be more important in driving the decision between which approach to use. The size of a pulp exposure may contribute to the decision between which VPT approach to use,[12] although it may be less important than previously thought. There is now evidence that exposures up to 2.5 mm can be predictably treated, but larger exposures (>2.5–5 mm) have a less predictable outcome.[2,23,24,25,26,27] More important than exposure size is the ability to control bleeding,[12,28,29] which is a likely indicator of the level of inflammation and may affect the seal achieved by a DPC material.[29] Where the pulp is vital and haemorrhage can be controlled, the tooth is a good candidate for a DPC.

The tooth should be isolated with rubber dam, especially when considering the importance of preventing bacterial contamination. Haemostasis should be attempted using a cotton pellet soaked in sodium hypochlorite (1–5%) and should be achieved in less than five minutes (Figures 1 and 2).[2,30] Following this, a calcium silicate cement (CSC; sometimes referred to as bioceramics) should be placed directly onto the pulp and the tooth restored with a definitive restoration, thus obtaining a definitive seal against bacterial and substrate ingress. Due to the long setting times of conventional CSCs and even newer CSCs (for example, Biodentine),[31] it may be necessary to place a glass ionomer cement (GIC) or self-etching resin (for example, RelyX Unicem 2) over the DPC before placing a definitive restoration. Delaying the placement of a definitive restoration may be associated with a reduced prognosis.[32] The success of DPC procedures using CSCs in extensively carious teeth is reported to be 80.3–94.7% at 1–3 years in healthy or reversibly inflamed pulps.[16,30,33,34]

Fig. 1 Suggested decision tree encompassing options for managing deep caries. Note that, upon pulp exposure where bleeding is uncontrollable, further pulp is resected until controllable bleeding is reached, suggesting 'healthy' tissue. Partial or full pulpotomy procedures are now an option. Where 'healthy' tissue is never reached, pulpectomy and conventional endodontics is indicated



Partial and full pulpotomy

Pulpotomy procedures using calcium hydroxide ($Ca[OH]_2$) were first described by Bernhard Hermann in 1920.[35] Cvek recognised that only part of the coronal pulp required excising and first described the 'partial pulpotomy' for traumatised incisors in 1978 (now known as the 'Cvek' pulpotomy),[36] which was later translated into carious exposures in 1993.[37] Pulpotomy techniques now have a large body of evidence showing clinical success.[3,38,39,40,41,42,43,44,45] Similar success rates for pulpotomies and pulpectomy followed by subsequent root filling have been identified,[41] making pulpotomy techniques a viable alternative.

Definitions for partial or full pulpotomies are described in Table 2. The rationale for pulpotomy is that cariously exposed pulps may be contaminated by bacteria, as well as other debris from the caries removal process, and it aims to remove inflamed, necrosing or necrotic pulp tissue, leaving a healthy, functioning pulp with a regenerative capacity.[25]

Aguilar and Linsuwanont (2011) completed a meta-analysis looking at DPCs and partial and full pulpotomies using CSCs.[3] In the short term (6–12 months), all three approaches were successful (87.5–97.6%), but in the longer term (>3 years), pulpotomy (full or partial) was more successful. This emphasises the need to consider resecting to healthy pulp once exposed and, although it may be counter-intuitive for such a procedure, it may be better to be slightly less conservative in pulp tissue removal.

Despite some studies finding parity between CSCs and $Ca(OH)_2$ when used for pulpotomies,[25] there is emerging evidence that CSCs offer superior outcomes in the longer term, including cases where there are signs of irreversible pulpitis.[43] Success of full pulpotomy procedures using CSCs is reported to be 92–95% in healthy pulps or those with reversible pulpitis at one year[40] and 71.3–95% in teeth with either reversible or irreversible pulpitis at 1–5 years.[39,41,42,46] Interestingly, one study found no difference in outcome (in terms of maintaining pulp vitality) between pre-operative reversible and irreversible pulpitis for pulpotomy procedures.[38] Partial pulpotomy success in teeth with pre-operative reversible or irreversible pulpitis is reported to be 85–98.4% at 1–2 years.[24,43,44] The use of a definitive full pulpotomy in cases of irreversible pulpitis has an increasing evidence base behind it and shows potential as an alternative to conventional endodontics.[4]

As with DPCs, haemorrhage should be controlled using a cotton wool pellet (soaked in 0.5–5% sodium hypochlorite) (Figures 1 and 3). Where haemorrhage cannot be controlled within five minutes, further pulp tissue may be removed using sterile burs under rubber dam, progressing from a partial pulpotomy to a complete pulpotomy. This may also be considered where there are signs or symptoms of irreversible pulpitis.[2] Certainly where 'moderate pulpitis' is identified (Table 1),[11] these are good candidates for pulpotomy, providing haemorrhage can be controlled.

In all cases, a CSC should be placed directly onto the pulp tissue.[2] Again, considering the importance of bacterial contamination, a definitive restoration should be placed as soon as possible to prevent bacterial ingress.

Material considerations

Given that the prevention of subsequent bacterial ingress is considered to be a key determinant in maintaining pulp vitality,[17,18] dentine bridge formation, dentine bonding and solubility will all be important considerations in material selection for VPT. Biocompatible materials that will promote pulpal healing are required. $Ca(OH)_2$ and CSCs have been used with varying degrees

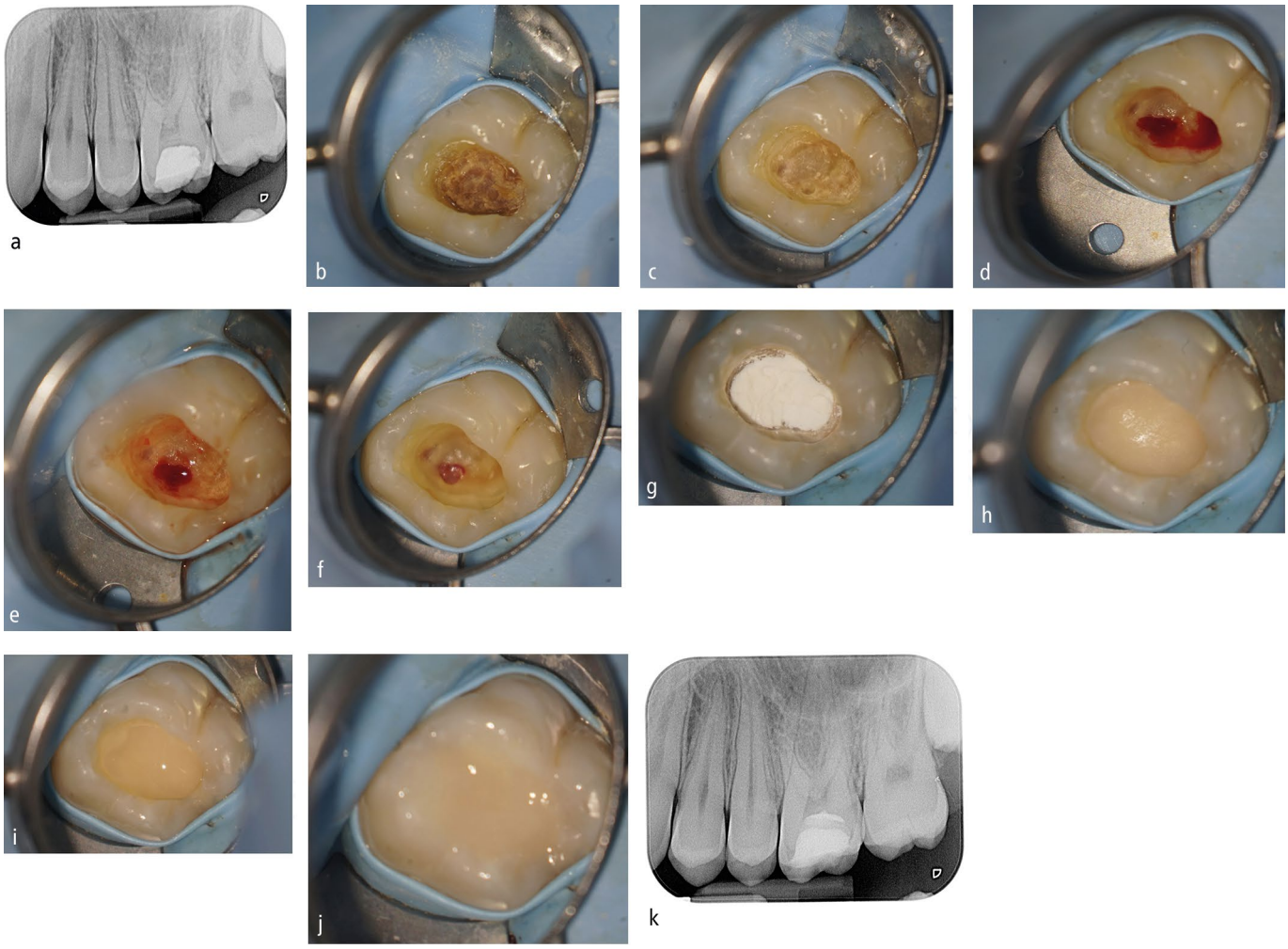


Fig. 2 Direct pulp cap: patient presented with worsening sensitivity to cold following attempted indirect pulp cap. The tooth was initially restored with interim GIC as part of a stepwise excavation technique; however, the patient presented with worsening sensitivity to cold, but no spontaneous pain. Clinical diagnosis: reversible pulpitis 26. a) Initial presentation of secondary caries under a deep composite. b) Presence of soft caries centrally after GIC removal. c) Soft dentine remained over pulp chamber. d) Removal of soft dentine resulted in exposure showing hyperaemic pulp. e) Partial pulpotomy performed using sterile bur to depth of around 2 mm. f) Control of bleeding achieved following application of 2.5% sodium hypochlorite on a cotton wool pellet for five minutes. g) Application of MTA directly to pulp. h) Application of GIC over MTA. i) Use of bulk-fill composite. j) Final application of definitive capping composite restoration. k) Post-operative radiograph showing direct pulp cap at six months (images courtesy of Luca Moranzoni and Jonathan Cowie)

of success. $Ca(OH)_2$ was initially established as the material of choice for DPCs because of its inhibition of bacterial growth and stimulation of reparative dentine.[47,48,49,50,51,52,53] More recently, CSCs have emerged as a more predictable alternative.

Calcium silicate cements

MTA was introduced as a root-end filling material over 25 years ago and was largely based on Portland cement consisting of calcium oxide, silicon dioxide and bismuth oxide.[54] Once hydrated, they release $Ca(OH)_2$,[55] accounting for their high pH.[56] Once set, they develop high compressive strength[57] and are considered to be of low solubility,[56] in contrast to $Ca(OH)_2$ (Table 3).

CSCs have excellent sealing ability, especially compared to $Ca(OH)_2$, which may be important in preventing the ingress of microorganisms.[58,59] CSCs are considered moderately antibacterial, mainly against facultative anaerobes,[56] and are reported to be of higher biocompatibility than $Ca(OH)_2$.[60]

A number of studies have found the dentine bridge in DPCs forms more quickly and is thicker with less tunnel defects where CSCs are used compared to $Ca(OH)_2$.[54,60,61,62,63,64,65,66] This dentine bridge may help prevent bacterial ingress,[67] and may therefore help explain the increasing failure of $Ca(OH)_2$ DPCs observed over time.[16,23,30,68,69] CSCs also induce less prolonged and lower levels of pulp inflammation and necrosis during healing compared to $Ca(OH)_2$.[51,54,60,63,64,65,66]

Newer synthetic CSCs have similar properties to MTA, but have refined the constituents to improve their mechanical and handling properties. This results in a higher sheer bond strength,[70] foregoing some of the disadvantages of MTA, such as the long setting time. The bismuth oxide in earlier MTA materials was reported to cause significant discolouration, but newer synthetic CSCs (for example, Biodentine [Septodont, St Maur-des-Fossés, France]) have been reported to cause less tooth discolouration.[71,72,73,74] Alterations in composition mean that there are now a wide range of CSCs available for a number of applications.

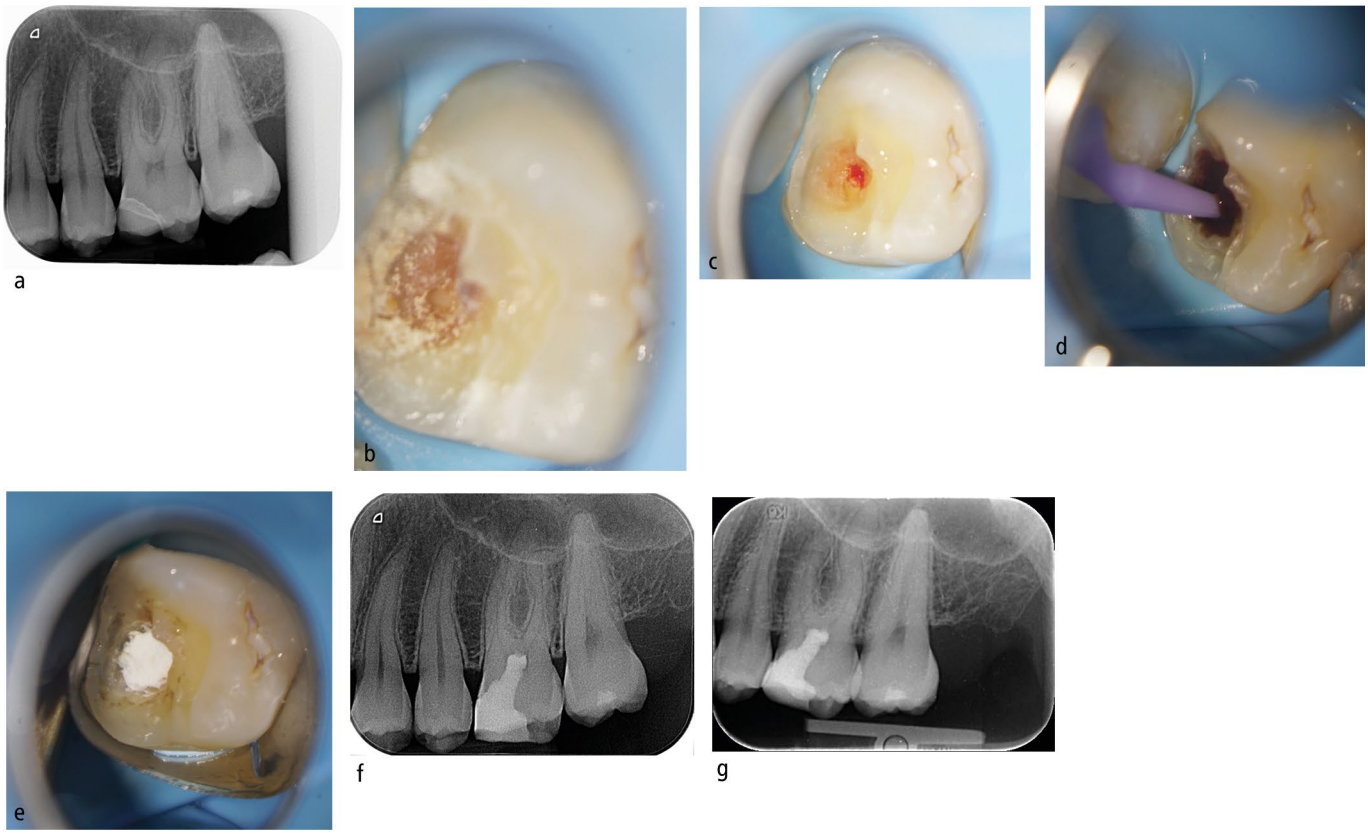


Fig. 3 Full pulpotomy: clinical diagnosis of irreversible pulpitis 26. a) Periapical radiograph showing deep caries under onlay 26 with possible slight apical radiolucency palatal root. b) Presentation following gross caries removal with soft dentine remaining over pulp. c) Pulp exposure following hand excavation. d, e) Bleeding could not be controlled within five minutes using microbrush soaked in 2.5% hypochlorite so a full pulpotomy was completed until healthy vital pulp was reached. f) Six-month review periapical radiograph following full pulpotomy, showing the preservation of tooth tissue compared to conventional endodontics. g) Twelve-month review periapical radiograph showing no increase in apical radiolucency. Tooth has remained symptom-free (images courtesy of Luca Moranzoni and Jonathan Cowie)

Table 3 A comparison of the key material properties of calcium silicate cements and calcium hydroxide for vital pulp therapies

Property	Calcium hydroxide	Calcium silicate cements
Sealing ability	Poor	Good
Compressive strength	Low	High
Solubility	High	Low
Biocompatibility	Moderate	High
Antibacterial properties	Good	Good
Setting time	Fast	Moderate
Dentine bridge	Slow formation, unpredictable, poor quality, thin	Rapid formation, predictable, high quality, thick

One concern of VPTs with CSCs is the perceived problems of re-access because of pulp sclerosis, given that they actively encourage the formation of a dentine barrier. Subsequent endodontics may therefore be more challenging.

Materials and treatment outcome

For DPCs, there is significant evidence that MTA or CSCs perform better than $Ca(OH)_2$ both histologically and in terms of the maintenance of vitality. Success of DPCs using $Ca(OH)_2$ has been reported to range from 21.3–80.1% at 1–13 years.[24,68,69]

Despite difficulties undertaking trials for a relatively rare and unplanned event, two recent randomised controlled trials have demonstrated a statistically significant improved outcome for MTA compared to $Ca(OH)_2$ for DPCs at 1–3 years,[30,34] and a recent systematic review concluded that there is now strong evidence for CSC's superiority over $Ca(OH)_2$.[75] Overall, considering all available evidence, there is sufficient evidence to recommend CSCs ahead of $Ca(OH)_2$ for DPCs.[3,16,22,23,30,34,68,69,76,77,78] There is emerging evidence that newer CSCs and traditional MTA perform similarly for DPCs, which is not surprising due to their fundamental similarities. A recent study found no significant difference between MTA and Biodentine up to three years (Biodentine success = 91.7%, MTA success = 96.0%).[79]

Evidence for pulpotomies is less clear. Two randomised controlled trials considering radiographic and clinical findings found no significant difference between $Ca(OH)_2$ and MTA used for pulpotomies in permanent molars with healthy pulps or reversible pulpitis,[80,81] and a recent meta-analysis found no significant difference between $Ca(OH)_2$ and MTA in mature teeth, with both materials having favourable outcomes.[82]

However, in mature molars with irreversible pulpitis, a recent randomised controlled trial found a superior success rate using the partial pulpotomy technique with MTA over $Ca(OH)_2$.[43] The latest European Society of Endodontology (ESE) position statement recommends using CSCs for complete or partial pulpotomies.[2]

Prognostic considerations in VPT

Pulp exposures may be categorised as:

1. Type 1 – traumatic, iatrogenic/mechanical, carious exposure through sound dentine with no pre-operative deep caries, in which case the pulp will not be significantly inflamed; or
2. Type 2 – carious exposure through deep caries, where there is an assumption that there is more extensive inflammatory change.[2,83]

There is conflicting evidence around the significance of the type of exposure on the outcome of VPT.[36,38,69,84,85,86] Although the type of exposure may affect prognosis, operative technique must always include rubber dam isolation and disinfection with sodium hypochlorite.

The location of the exposure is also an important determinant, with better success reported in occlusal rather than proximal exposures.[28,34,85,86]

Age may also be an important prognostic indicator for the success of VPTs, more so than for deep caries management using indirect pulp caps (IPCs), selective caries removal or stepwise excavation.[87] Teeth may respond differently to VPT depending on their maturity, vascularity and degree of previous degeneration.[86] The older a permanent tooth, the more secondary and potentially tertiary dentine is present in the pulp. Allied with an increased pulpal fibrosity, this results in a reduced blood supply, which is considered key to its regenerative capacity.[1,88,89] How this translates into clinical outcomes has been debated, but there is considerable evidence suggesting decreasing success with age.[24,33,83,84,90] It is acknowledged that other studies have not identified this trend.[17,42]

ESE guidelines for VPT recommend attempting to control haemorrhage using a cotton pellet soaked in 0.5–5% sodium hypochlorite (first choice) or 0.2–2% chlorhexidine for five minutes.[2] The five-minute guideline is derived from expert opinion, but there is evidence that inability to control bleeding may lead to decreased success in DPCs,[12] reinforcing the need to use direct clinical observation in diagnosis and decision-making. The use of sodium hypochlorite or chlorhexidine aims to control bleeding while also disinfecting the dentine and superficial pulp. Again, there is no robust evidence to support this recommendation, but it has become established practice in published research.

Follow-up

A successful VPT procedure is defined as 'absence of symptoms and maintenance of pulp vitality after at least one year'.[2] The ESE recommend a 6- and 12-month review following any VPT procedure, after which annual review is recommended for up to four years, if required. This should include history taking, sensibility testing and radiography to identify any periapical periodontitis. This almost aligns with FGDP selection criteria for endodontic radiography.[91] Radiographs may be considered, even where teeth are symptom-free, with additional periapical pathology identified despite the assumption of success.[18] In the future, limited field CBCT may be of use for more comprehensive evaluation of the periapical status following management of deep caries with GIC and Biodentine for IPCs;[92] however, there must be clear and strong justification for the increased radiation exposure with a net benefit to the patient (that is, a likely change in treatment approach).[8,93]

Caution must be applied to pulp testing in teeth that have received a full pulpotomy, as they may not respond in a similar way to adjacent or contralateral teeth to electric pulp testing or cold thermal tests. As a result, studies evaluating the outcome of pulpotomies tend to rely more on radiography and CBCT. Caution should also be applied to the assessment of colour, given that CSCs are capable of discolouring teeth to variable degrees,[56] albeit less than traditional MTA.

Conclusion

VPTs using CSCs should be recommended as first-line treatments for frank exposures of the vital dental pulp, when isolation of the tooth is possible and bleeding can be controlled. Where symptoms are suggestive of irreversible pulpitis, exposing the pulp and cutting back to healthy pulp tissue before placing a CSC is a viable alternative to conventional pulpectomy and endodontics. However, long-term outcome studies are required to provide robust evidence to support VPT in addition to the opinion and guidance of specialist societies.

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Conflict of interest

The authors declare no conflict of interests.

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