UK National Clinical Guidelines in Paediatric Dentistry

This revised Clinical Guideline in Paediatric Dentistry replaces the previously published eighth Guideline entitled 'The pulp treatment of the primary dentition' [Llewelyn, 2000]. The process of guideline production began in 1994, resulting in first publication in 1997. Each guideline has been circulated to all Consultants in Paediatric Dentistry in the UK, to the Council of the British Society of Paediatric Dentistry, and to people of related specialties recognised to have expertise in the subject. In the case of the present guideline, an internationally recognised expert on primary pulp therapy was invited to be a co-author (ABF). The final version of the guideline is produced from a combination of this input and thorough review of the published literature. The intention is to encourage improvement in clinical practice and to stimulate research and clinical audit in areas where scientific evidence is inadequate. Evidence underlying recommendations is scored according to the SIGN classification and guidelines should be read in this context. For those wishing further detail, the process of guideline production in the UK is described in the International Journal of Paediatric Dentistry 1997; 7: 267–268.

Pulp therapy for primary molars

H. D. RODD, P. J. WATERHOUSE, A. B. FUKS, S. A. FAYLE & M. A. MOFFAT

Introduction

Management of the grossly carious primary molar is a common but sometimes challenging aspect of dental care for young children. Regrettably, the caries experience of British 5-year-olds looks unlikely to improve in the foreseeable future [Pitts *et al.,* 2005]. It is therefore essential that clinicians are both confident and competent in selecting and undertaking the most appropriate treatment for grossly carious primary molars.

In view of new insights into primary pulp biology [Rodd and Boissonade, 2001, 2002, 2005], developments in pulpal medicaments and worldwide changes in clinical practice, it was felt necessary to update the previous Clinical Guideline on pulp treatment for the primary dentition [Llewelyn, 2000]. It is hoped that this revised guideline will continue to facilitate good decision-making and evidence-based practice for young patients. However, with continued advancement and availability of bioactive pulp medicaments additional revisions to this guideline may be indicated in future years [Goldberg, 2003].

Correspondence: Professor Helen Rodd, Department of Oral Health and Development, School of Clinical Dentistry, Sheffield, UK. E-mail: h.d.rodd@sheffield.ac.uk

1. Treatment planning

The first treatment decision for the young patient with one or more extensively carious primary molars is whether to retain or extract these teeth. Any treatment plan should be based on a thorough history, examination and appropriate investigations. It should also take into account the patient's social, medical and dental status.

1.1 Diagnosis

It is important to try to provisionally diagnose the likely pulpal status of the tooth concerned, as this will determine the most appropriate treatment.

1.1.1 Clinical signs and symptoms

The following symptoms and clinical signs are likely to be associated with significant pulpal inflammation and pathology:

- Any history of spontaneous severe pain, particularly at night
- Reported pain on biting
- The necessity for analgesics

- The clinical extent of the caries, notably the presence of marginal ridge breakdown
- The presence of any intra-oral swelling or sinus
- A history of intra-oral or facial swelling

1.1.2 Special investigations
- Gentle finger pressure may determine whether the tooth is mobile or tender
- Pulpal sensibility testing is not appropriate for primary molars
- Radiographs are usually mandatory as these provide further important information about the extent of the caries, the proximity of large restorations to a pulp horn, presence of any periradicular pathology, degree of pathological or physiological root resorption, and presence of a successor

1.2 Indications for tooth retention

1.2.1 Medical factors
- Patients 'at risk' from an extraction (e.g. bleeding disorders, hereditary angio-oedema)
- Patients 'at risk' if a general anaesthetic is required for tooth removal (e.g. some cardiac conditions, cystic fibrosis, muscular dystrophies)

1.2.2 Dental factors
- Minimal number of extensively carious primary molars likely to require pulp therapy (<3)
- Hypodontia of the permanent dentition
- Where prevention of mesial migration of first permanent molars is desirable

1.2.3 Social factors
- A regular attender, with good compliance and positive parental attitudes

1.3 Indications for tooth removal

1.3.1 Medical factors
- Patients 'at risk' from residual infection (e.g. immunocompromised, susceptibility to infective endocarditis)

1.3.2 Dental factors
- Tooth unrestorable after pulp therapy
- Extensive internal root resorption
- Large number of carious teeth with likely pulpal involvement (>3)
- Tooth close to exfoliation ($>2/3$ root resorption)
- Contralateral tooth already lost (in the case of a first primary molar, and if indicated orthodontically)
- Extensive pathology or acute facial swelling necessitating emergency admission

1.3.3 Social factors
- An irregular attender, with poor compliance and unfavourable parental attitudes.

2. Treatment options

2.1 Indirect pulp treatment

This approach has gained increased worldwide popularity in recent years.

2.1.1 Rationale
- To arrest the carious process and provide conditions conducive to the formation of reactionary dentine beneath the stained dentine and remineralisation of remaining carious dentine
- To promote pulpal healing and preserve/maintain the vitality of pulp tissue

2.1.2 Indications
- Tooth with a deep carious lesion
- No signs or symptoms indicative of pulpal pathosis

2.1.3 Procedure
- Local anaesthetic
- Good isolation with rubber dam
- Removal of all caries at the enamel-dentine junction
- Judicious removal of soft deep carious dentine (using hand excavators or a slowly rotating large round steel bur) lying directly over the pulp region with care to avoid a pulpal exposure
- Placement of appropriate lining material such as a reinforced glass ionomer cement, a hard-setting calcium hydroxide or zinc oxide eugenol.
- Definitive restoration to achieve optimum external coronal seal (ideally an adhesive restoration or preformed crown)

2.1.4 Clinical outcome
- $>90\%$ clinical success (absence of symptoms or pathology) at 3 years follow up

2.1.5 Level of evidence (Grade B)
Evidence has been obtained from a number of well-designed retrospective descriptive studies.

2.2 Direct pulp capping

This approach has limited application and is generally not recommended for primary molars.

2.2.1 Rationale
- To encourage the formation of a dentine bridge at the point of pulpal exposure with preservation of pulpal health and vitality

2.2.2 Indications
- Asymptomatic tooth
- Small traumatic (non-carious) pulpal exposure
- An exposure in older child (1–2 years prior to normal exfoliation of the tooth). In these cases treatment failure would not imply the need for a space maintainer following extraction, as it would in younger children

2.2.3 Procedure
- Local anaesthetic
- Optimum isolation with rubber dam
- Gentle application of cotton pledget soaked in water/saline to stem any pulpal haemorrhage
- Application of hard-setting calcium hydroxide paste or mineral trioxide aggregate (MTA)
- Definitive restoration to achieve optimum external coronal seal (ideally an adhesive restoration or preformed metal crown)

2.2.4 Clinical outcome
- Prognosis is reported to be generally poor.

2.2.5 Level of evidence (Grade C)
No studies of good quality are available thus recommendations are based on clinical experience and expert opinion.

2.3 Pulpotomy

A pulpotomy entails the removal of the coronal pulp and maintenance of the radicular pulp. There are three main approaches to this technique: i) preserving the radicular pulp in a healthy state; ii) rendering the radicular pulp inert, or iii) encouraging tissue regeneration and healing at the site of radicular pulp amputation.

2.3.1 Rationale
- To remove the coronal pulp, which has been clinically diagnosed as irreversibly inflamed, leaving behind a possibly healthy or reversibly inflamed radicular pulp

2.3.2 Indications
- Asymptomatic tooth or only transient pain (see explanatory notes 1.1.1)
- A carious or mechanical exposure of vital coronal pulp tissue

2.3.3 Procedure
- Local anaesthetic
- Good isolation with rubber dam
- Removal of caries
- Complete removal of roof of pulp chamber preferably with a non-end cutting bur
- Removal of coronal pulpal tissue with sharp sterile excavator or large round bur in a slow handpiece
- Attain initial radicular pulpal haemostasis by gentle application of sterile cotton pledget moistened with saline (haemostasis should be achieved within four minutes)
- Selection of medicament for direct application to radicular pulp stumps to include any of the following:

1) 15.5% ferric sulphate solution (Astringedent™, Ultradent Products Inc., Salt Lake City, UT) burnished on pulp stumps with microbrush for 15 seconds to achieve haemostasis, followed by thorough rinsing and drying
2) 20% (1:5 dilution) Buckley's formocresol solution applied to radicular pulp on a cotton pledget for five minutes to achieve superficial tissue fixation
3) MTA paste applied over radicular pulp with proprietary carrier
4) Well-condensed layer of pure calcium hydroxide powder applied directly over radicular pulp

[N.B. In cases of uncontrollable pulpal haemorrhage, an alternative approach may need to be considered such as root canal treatment or extraction]

- Application of a lining (if appropriate) such as reinforced glass ionomer or zinc oxide eugenol cement
- Definitive restoration to achieve optimum external coronal seal (ideally an adhesive restoration of preformed metal crown)

2.3.4 Clinical outcome
The available evidence suggests that the formocresol pulpotomy, the ferric sulphate pulpotomy, electrocautery or pulpectomy are equally successful techniques. More recent studies are also reporting good success rates with the use of MTA (grey and white formulations) in pulpotomised primary molars. Long-term success rates for the use of calcium hydroxide in primary molar pulpotomy appear to be lower than for other approaches.

2.3.5 Level of evidence (Grades A and B)
Evidence is available from meta-analysis; randomised controlled trials and other well conducted clinical studies.

2.4 Desensitising pulp therapy

2.4.1 Rationale
- To reduce pulpal inflammation and/or symptoms in order to facilitate subsequent pulpotomy or pulpectomy procedure

2.4.2 Indications
- Carious pulpal exposure but no signs/symptoms of loss of vitality
- Non-compliant child who may require inhalation sedation for further treatment
- Hyperalgesic pulp (adequate analgesia not achieved)

2.4.3 Procedure
- Local anaesthetic
- Good isolation with rubber dam
- Removal of caries
- Place a small pledget of cotton wool loaded with steroidal antibiotic paste (Ledermix^{TM}) directly over exposure site (tooth is usually too sensitive to remove entire roof of pulp chamber)
- Place a well-sealed temporary dressing (IRM - without undue pressure) over the cotton pledget
- Recall after 7–14 days and proceed with a pulpotomy or pulpectomy technique (depending on clinical findings)

2.4.4 Clinical outcome
- The effectiveness of Ledermix paste as a desensitising medicament for cariously exposed primary molars has not been widely reported in the literature. However, its anti-inflammatory and analgesic properties have been well documented in permanent teeth of adults
- The success rate for the use of Ledermix^{TM} as a pulpotomy agent in primary teeth is not well documented

2.4.5 Level of evidence (Grade C)
No studies of good quality are available thus recommendations are reserved for cases where good anaesthesia can not be achieved or there is initial poor patient compliance.

2.5 Pulpectomy
It is acknowledged that primary molar radicular morphology, inherent physiological root resorption and the close proximity of the permanent successor tooth are complicating factors in the pulpectomy procedure. However, primary molar pulpectomy is achievable with practice and appropriate patient selection.

2.5.1 Rationale
- To remove irreversibly inflamed or necrotic radicular pulp tissue and gently clean the root canal system
- To obturate the root canals with a filling material that will resorb at the same rate as the primary tooth and be eliminated rapidly if accidentally extruded through the apex

2.5.2 Indications
- Tooth diagnosed as having irreversible pulpitis on basis of reported symptoms and /or clinical findings (e.g. profuse haemorrhage following pulpotomy procedure)
- Non-vital radicular pulp with/without associated infection
- Good patient compliance

2.5.3 Procedure

A one- or two-stage pulpectomy may be undertaken depending on whether the radicular pulp is irreversibly inflamed or non-vital (with/without an associated periradicular pathosis). If infection is present, and the presence of an exudates does not allow drying of the canal, consideration should be given to the two-stage pulpectomy technique, where the root canals may be dressed with an antimicrobial agent for 7–10 days and subsequently obturated at the second visit.

- Pre-operative radiograph showing all roots and their apices
- Local anaesthetic (to enable use of rubber dam clamp)
- Rubber dam mandatory
- Removal of caries
- Removal of roof of pulp chamber preferably with non-end cutting bur
- Removal of any remains of coronal pulp tissue with sharp sterile excavator or large bur in slow handpiece
- Note whether radicular pulp is bleeding (one-stage procedure) or necrotic (usually requiring two-stage procedure)
- Identify root canals
- Irrigate with normal saline (0.9%), Chlorhexidine solution (0.4%) or sodium hypochlorite solution (0.1%)
- Estimate working lengths of root canals keeping 2 mm short of the radiographic apex
- Insert small files (no greater than size 30) into canals and file canal walls lightly and gently
- Irrigate the root canals
- Dry canals with pre-measured paper points, keeping 2 mm from root apices
- If infection present (canal exudate and/or associated sinus) dress root canals with non-setting calcium hydroxide and temporise (two-stage procedure). Consider prescribing a systemic antimicrobial
- If canals can be dried with paper points, obturate root canals by injecting or packing a resorbable paste e.g. slow-setting pure zinc oxide eugenol, non-setting calcium hydroxide paste or calcium hydroxide and iodoform paste (Vitapex^{TM} or Endoflas^{TM})

- Definitive restoration to achieve optimum external coronal seal (ideally a preformed crown)

2.5.4 Clinical outcome
- 86% clinical success at 36 months follow up (lower success rates found at longer follow-up times)

2.5.5 Level of evidence (Grade B)
Evidence is available from randomised controlled trials and other well conducted clinical studies.

2.6 Review

Regular clinical and radiographic review following any primary molar pulp therapy is mandatory.

Explanatory notes

1. Treatment planning

1.1 Diagnosis

1.1.1 Clinical signs and symptoms
It is important to take a good history of the presenting symptoms. This will aid assessment of the likely pulpal status of the tooth concerned and will therefore help determine the most appropriate treatment [Fuks, 2000]. Although correlation between symptoms and pulpal status is known to be quite poor [Guthrie *et al.,* 1965], Seltzer and Bender [1984] found that a high percentage of teeth with spontaneous pain demonstrated irreversible pulpitis. A pulpotomy procedure is therefore not indicated for any tooth with unprovoked continuous pain. However, care should be taken not to misinterpret a throbbing pain, simulating an irreversible pulp condition, with that associated with an inflamed dental papilla owing to food impaction. These symptoms generally disappear following restorative treatment [Fuks, 2005]. Conversely, the absence of pain does not indicate a pulp free from widespread inflammation or necrosis.

In teeth with carious breakdown of more than half of the buccolingual intercuspal distance, there are likely to be some inflammatory changes within the pulp horn region [Duggal *et al.,* 2002]. In such teeth, some form of conservative pulpal therapy, possibly indirect pulp treatment, is thus usually indicated.

1.2 Indications for tooth retention

1.2.3 Dental factors
Retention of second primary molars is usually advisable to prevent or minimise mesial drift of first permanent molars. This may be of benefit in reducing subsequent premolar crowding and/or avoiding the establishment of undesirable buccal relationships.

1.3 Indications for tooth removal

1.3.3 Dental factors
In cases where a first primary molar has already been lost, extraction (rather than pulp treatment) of the contralateral first primary molar is usually recommended (unless the dentition is very spaced) to avoid subsequent centre line shift [Rock, 2002].

2. Treatment options

Once the decision has been made to retain the tooth, the clinician needs to select the most appropriate treatment option. A fundamental consideration is whether the pulp is likely to be vital or non-vital. A good history followed by a careful clinical examination and appropriate radiograph will frequently help in reaching a correct diagnosis and selecting the most appropriate treatment. However, on some occasions, once treatment has commenced, further empirical clinical findings, such as the presence of uncontrollable pulpal haemorrhage from the amputated radicular pulp stumps, may also aid treatment selection.

2.1 Indirect pulp treatment

2.1.3 Procedure
Some authors have recommended that indirect pulp treatment be undertaken as a two-stage procedure [Vij *et al,* 2004]. Initial caries removal is achieved without the use of local anaesthetic and a reinforced zinc oxide eugenol or glass ionomer cement restoration is placed for a 1–3 month period, prior to further caries removal under local anaesthetic [Falster *et al.,* 2002]. No precise method has been developed to determine how much caries to remove; it is reliant on good clinical judgement. This approach may have merit in young anxious patients but it is of paramount importance that the temporary restoration is not subject to microleakage. Conversely, other investigators have reported a higher success rate when indirect pulp treatment is performed as a single visit procedure [Farooq *et al,* 2000].

There is insufficient evidence to support the use of any one specific lining material for indirect pulp treatment [Ehrenreich, 1968]. However, newer research appears to be directed towards the use of glass ionomer cements [Massara *et al.,* 2002].

2.1.4 Clinical outcome
Several studies have reported success rates (an absence of symptoms or pathology) of over 90% at 3 years follow-up [Farooq *et al.,* 2000; Falster *et al.,* 2002; Al-Zayer *et al*., 2003; Vij *et al*., 2004]. It would appear that success is greater in second primary molars than first primary molars [Al-Zayer *et al*., 2003].

The success of the technique appears to be highly dependent on achieving a good external coronal seal, which will effectively cut off the nutritional supply for any remaining dentinal bacteria and will prevent further bacterial microleakage. It has been shown that failure is 7.7 times more likely in a tooth restored with an amalgam than one restored with a performed metal crown [Al-Zayer *et al.,* 2003]. Adhesive restorations have also been shown to provide optimum protection from marginal leakage in pulpotomised primary molars [Guelmann *et al.,* 2004]. It is therefore strongly recommended that adhesive restorations or preformed crowns are employed following any primary molar pulp therapy procedure.

2.2 Direct pulp capping

2.2.4 Clinical outcome

Although some clinical success has historically been reported for direct pulp capping of primary teeth [Hargreaves, 1969], the technique is not normally advocated for carious primary molars [American Academy of Pediatric Dentistry, 2004]. No long-term outcome data are available but prognosis is reported to be generally poor, with some studies reporting a high incidence of internal resorption [Starkey, 1963; Kopel, 1992]. Interestingly, a recent case report described the use of MTA (ProRoot, Dentsply) in a cariously exposed primary molar and reported clinical success at 18 months follow up [Bodem *et al.,* 2004]. However, further studies will be required before such a technique is universally recommended.

2.3 Pulpotomy

2.3.3 Procedure

- Formocresol

A key factor to prompt revision of the existing Clinical Guidelines was the perceived need to re-evaluate the use of formocresol. The dental profession has always expressed some reservations about the use of formocresol, or more specifically formaldehyde, in primary molar pulp treatment [Waterhouse, 1995]. In a recent survey of 184 British paediatric dentistry specialists, 54% expressed concern about the safety of formocresol [Hunter and Hunter, 2003]. In June 2004, a press release from the International Agency of Research on Cancer (IARC) stated that there was now considered to be '*sufficient evidence that formaldehyde causes nasopharyngeal cancer in humans*' [IARC, 2004]. Studies linking formocresol with nasopharyngeal cancer in both humans and animals are based on chronic exposure to formaldehyde at very high doses [Swenburg *et al.,* 1980]. There is also strong, but as yet inconclusive, evidence of a causal relationship between formaldehyde exposure and leukaemia [IARC, 2004; Collins and Lineker, 2004].

Occupational formaldehyde exposure occurs in numerous industrial settings but strict regulations are in place to monitor and reduce worker exposure [National Institute for Occupational Safety and Health, 1981]. The actual amount of formaldehyde vapour exposure (ppm) to a child undergoing a formocresol pulpotomy is unknown. More importantly, the degree and potential effect of accumulative formaldehyde exposure to dental professionals is also unknown.

There appears to be conflicting opinion amongst British paediatric dentists as to the justification for continued use of formocresol. It is, however, anticipated that the availability of formocresol will become increasingly problematic and may actually drive a change in clinical practice. It is the intention of this Guideline to highlight current concerns regarding formaldehyde and to suggest that routine use of the formocresol pulpotomy may be imprudent given the availability of effective alternatives (ferric sulphate and MTA) [Srinivasan *et al*., 2006]. As in all areas of clinical practice, careful consideration should be given to the perceived benefits of any intervention versus the potential risks.

- Ferric sulphate

Ferric sulphate promotes pulpal haemostasis through a chemical reaction with blood. It has been proposed as a pulpotomy agent on the basis that it controls pulpal bleeding and forms a 'protective' metal-protein clot over the underlying vital radicular pulp. A zinc oxide eugenol base is then usually applied over the radicular pulpal tissue. However, a number of authors have speculated that the eugenol may in fact promote internal resorption when placed in contact with vital tissue following a ferric sulphate pulpotomy [Smith *et al*., 2000; Casas *et al*., 2003]. This possible complication warrants further investigation.

- Mineral trioxide aggregate

Mineral trioxide aggregate has been used successfully in adult endodontic procedures since the early 1990s [Lee et al., 1993]. The constituents include: tricalcium silicate, dicalcium silicate, tricalcium aluminate, tetracalcium aluminoferrite, calcium sulphate and bismuth oxide. The material has excellent bioactive properties and essentially stimulates cytokine release from pulpal fibroblasts, which in turn stimulates hard tissue formation. It is mixed with sterile water to a sandy consistency, which is gently packed against the

radicular pulp stumps. The material is hydrophilic and takes up to four hours to set completely.

• Other pulpotomy procedures

Although not commonly used by British paediatric dentists, electrosurgery has been well described as a non-pharmacological haemostatic pulpotomy approach for carious primary molars. The procedure carbonises and denatures superficial pulp tissue producing a layer of coagulative necrosis with healthy radicular pulp beneath it. Success rates are reported to be similar to those achieved with a formocresol pulpotomy [Dean *et al.,* 2002; Rivera *et al.,* 2003]. However, the electrosurgical technique will not eliminate inflammation within pulp tissue and success is therefore reliant upon the initial inflammatory status of the radicular pulp. To date there has been limited research on the use of lasers in human primary molar pulpotomy.

2.3.4 Clinical outcome

A recent systematic review of pulp therapy for primary molars [Nadin *et al.,* 2003] identified three randomised controlled clinical trials where the follow up period had been at least 12 months. From the findings of these studies, it was concluded that the formocresol pulpotomy, the ferric sulphate pulpotomy, electrocautery or pulpectomy were equally successful techniques [Ibricevic *et al.*, 2000; Dean *et al.*, 2002; Casas *et al.*, 2003, 2004]. A recent meta-analysis of formocresol versus ferric sulphate primary molar pulpotomies found both approaches to have a similar rate of clinical and radiographic success [Loh *et al.,* 2004].

The clinical and radiographic success of ferric sulphate pulpotomies is generally reported as being $>90\%$ at 2 years [Fuks *et al.*, 1997; Smith *et al.,* 2000; Casas *et al.,* 2003]. More recent studies are reporting very good success rates with the use of MTA in pulpotomised primary molars. The use of grey and white formulation MTA has been found to be 100% and 90% respectively at a 12-month follow up period [Agamy *et al.,* 2004]. Holan and co-workers [2005] achieved a 97% clinical and radiographic success rate for MTA pulpotomies as compared to an 83% success rate for formocresol pulpotomies.

Long-term success rates for the use of calcium hydroxide in vital primary molar pulpotomy appear to be lower than for other approaches. The main reported complication is internal root resorption, which is attributed to the presence of an extravascular blood clot [Schroder, 1971]. However some studies have reported favourable outcomes in over 80% of cases [Heilig *et al.*, 1984; Gruythuysen and Weerheijm, 1997].

It should be appreciated that, although studies report high levels of clinical success following pulpotomy procedures, radiographic findings often indicate some pathological changes, which most commonly include calcific metamorphosis and internal resorption [Smith *et al.*, 2000]. Casas and colleagues [2003] noted that 55% of their ferric sulphate-treated molars showed some radiographic evidence of internal resorption and 71% demonstrated pulp canal obliteration. Papagiannoulis [2002] reported that the internal resorption, present in some ferric sulphate treated teeth, did not progress or even remineralise. Thus these changes are not considered potentially damaging to the underlying successor tooth, and as such, are not an indication of treatment failure.

2.4 Desensitising pulp therapy

2.4.3 Procedure

Historically, this two-stage technique used paraformaldehyde paste to fix and devitalise hypersensitive coronal pulp tissue. However, in view of increasing concerns about the use of formaldehyde, an alternative approach, using Ledermix™ paste, is recommended [Waterhouse, 2004]. Ledermix™ is a readily available paste containing triamcinalone acetonide (steroid) and demeclocycline (antimicrobial). It is used widely in adult endodontic procedures and has been shown to reduce pulpal inflammation and pain [Langeland *et al.,* 1977; Sazak *et al.,* 1996; Ehrmann *et al.,* 2003].

2.4.4 Clinical outcome

There have been no histological or clinical studies reporting the success of Ledermix™ as a desensitising medicament in primary pulp therapy. Interestingly, its use as a pulpotomy agent has been described with a reported success rate of 79% [Hansen, 1971].

2.5 Pulpectomy

2.5.3 Clinical procedure

Slow setting pure zinc oxide eugenol paste has traditionally been the material of choice as a primary molar root filling material. However, concerns have been expressed regarding the slow removal of zinc oxide eugenol by the body (if extruded though the root apex) and the differential rate of resorption between this material and the tooth itself [Fuks, 2000]. Recently investigators have found that Vitapex™ (a mixture of calcium hydroxide and iodoform paste) has a superior success rate to that of zinc oxide eugenol (100% versus 78.5% at 16 months) and is removed more readily if extruded through an apex [Mortazavi and Mesbahi, 2004].

Some clinicians have advocated the use of chemotherapeutic agents in infected primary molar teeth as a simpler option to pulpectomy [Ballesio *et al.,* 2002; Takushige *et al.,* 2004]. However, the medicaments used in these studies are not yet commercially available. Traditionally, British paediatric dentists have employed beechwood creosote to 'disinfect' non-vital primary molars in a two-stage 'non-vital pulpotomy' procedure, but this medicament is highly toxic [Duggal et al., 2005], not easily obtained and success rates are poor [Hobson, 1970]. In the light of the knowledge today, it would not be biologically acceptable to leave necrotic tissue in a root canal. Similarly, formocresol has also been in primary molars with irreversibly inflamed or necrotic radicular pulp tissue. In view of increasing concerns about formocresol, this approach is now also outmoded.

2.5.4 Clinical outcome

In a recent study, Casas [2004] reported an 86% success rate for pulpectomised primary molars, filled with zinc oxide eugenol, at 36 months follow up. The same study reported that pulpectomised primary molars showed significantly greater survival rates than those subject to a pulpotomy. Excellent success rates have also been reported where KRI paste or a calcium hydroxide and iodoform preparation has been employed [Nishino *et al*., 1980, Fuks *et al*., 2002]. It should also be noted that higher failure rates are generally reported where canals are overfilled as compared to underfilled [Holan and Fuks, 1993].

2.6 Review

Whilst the clinical success of many primary tooth pulp treatments is reportedly high, studies often demonstrate a much lower proportion of teeth with radiographic signs of complete healing. It should also be noted that radicular cyst development is a well-recognised sequelae [Savage *et al*., 1986; Takiguchi *et al*., 2001]. Hence, regular clinical and radiographic review following any primary molar pulp therapy is strongly recommended.

References

Agamy HA, Bakry NS, Mounir MF, Avery DR. Comparison of mineral trioxide aggregate and formocresol as pulp-capping agents in pulpotomised primary teeth. Pediatric Dentistry 2004; **26**: 302–309.

Al-Zayer MA, Straffon LH, Feigal RJ, Welch KB. Indirect pulp treatment of primary posterior teeth: a retrospective study. Pediatric Dentistry 2003; **25**: 29–36.

American Academy of Pediatric Dentistry. Guideline on pulp therapy for primary and young permanent teeth (revised), 2004. http://www.aapd.org/media/policies.asp.

Ballesio I, Campanella V, Gallusi G, Marzo G. Chemical and pharmacological shaping of necrotic primary teeth. European Journal of Paediatric Dentistry 2002; **3**: 133–138.

Bodem O, Blumenshine S, Zeh D, Koch MJ. Direct pulp capping with mineral trioxide aggregate in a primary molar: a case report. International Journal of Paediatric Dentistry 2004; **14**: 376–379.

Casas M, Kenny DJ, Layug MA. Two-year outcomes of primary molar ferric sulfate pulpotomy and root canal therapy. Pediatric Dentistry 2003; **25**: 97–102.

Casas M, Kenny DJ, Johnston DH, Judd PL. Long-term outcomes of primary molar ferric sulfate pulpotomy and root canal therapy. Pediatric Dentistry 2004; **26**: 44–48.

Collins JJ, Lineker GA. A review and meta-analysis of formaldehyde exposure and leukaemia. Regulatory Toxicology and Pharmacology 2004; **40**: 81–91.

Dean JA, Mack RB, Fulkerson BT, Sanders BJ. Comparison of electrosurgical and formocresol pulpotomy procedures on children. International Journal of Paediatric Dentistry 2002; **12**: 177–182.

Duggal MS, Nooh A, High A. Responses of the primary pulp to inflammation: a review of the Leeds studies and challenges for the future. European Journal of Paediatric Dentistry 2002; **3**: 111–114.

Duggal MS, Curzon MEJ, Balmer R, Roberts J. Potential toxicity (comment). British Dental Journal 2005; **198**: 563.

Ehrenreich DW. A comparison of the effects of zinc oxide and eugenol and calcium hydroxide on carious dentine in human primary molars. ASDC Journal of Dentistry for Children 1968; **35**: 451–456.

Ehrmann EH, Messer HH, Adams GG. The relationship of intracanal medicaments to postoperative pain in endodontics. International Endodontic Journal 2003; **36**: 868–875.

Falster CA, Araujo FB, Straffon LH, Nor JE. Indirect pulp treatment: in vivo outcomes of an adhesive resin system vs calcium hydroxide for the protection of the dentin-pulp complex. Pediatric Dentistry 2002; **24**: 241–248.

Farooq NS, Coll JA, Kuwabara A, Shelton P. Success rates of formocresol pulpotomy and indirect pulp therapy in the treatment of deep dentinal caries in primary teeth. Pediatric Dentistry 2000; **22**: 278–286.

Fuks AB. Pulp therapy for the primary and young permanent dentitions. Dental Clinics of North America 2000; **44**: 571–596.

Fuks AB. Pulp therapy for the primary dentition. In: Pinkham JR, editor: Pediatric Dentistry: Infancy Through Adolescence. Philadelphia: Saunders, 2005.

Fuks AB, Holan G, Davis JM, Eidelman E. Ferric sulfate versus dilute formocresol in pulpotomised primary molars: long-term follow up. Pediatric Dentistry 1997; **19**: 327–330.

Fuks AB, Eidelman E, Pauker N. Root fillings with Endoflas in primary teeth: a retrospective study. Journal of Clinical Pediatric Dentistry 2002; **27**: 41–45.

Goldberg M, Six N, Decup F, Lasfargues J, Salih E, Tompkins K, Veis A. Bioactive molecules and the future of pulp therapy. American Journal of Dentistry 2003; **16**: 66–76.

Gruythuysen RJ, Weerheijm KL. Calcium hydroxide pulpotomy with a light-cured cavity-sealing material after two years. ASDC Journal of Dentistry for Children 1997; **64**: 251–253.

Guelmann M, Bookmyer KL, Villalta P, Garcia-Godoy F. Microleakage of restorative techniques for pulpotomised primary molars. ASDC Journal of Dentistry for Children 2004; **71**: 209–211.

Guthrie TJ, McDonald RE, Mitchell DF. Dental hemogram. Journal of Dental Research 1965; **44**: 678–682.

Hansen HP, Ravn JJ, Ulrich D. Vital pulpotomy in primary molars. A clinical and histological investigation of the effect of

zinc-oxide eugenol cement and Ledermix. Scandinavian Journal of Dental Research 1971; **79**: 13–23.

Hargreaves JA. Maintenance of exposed primary deciduous teeth with ledermix. In: Odontoiatria Infantile: Proceedings of the 2nd International Symposium of the International Association of Dentistry for Children. Rome: Italian Society of Dentistry for Children, 1969: 279–289.

Heilig J, Yates J, Siskin M, McKnight J, Turner J. Calcium hydroxide pulpotomy for primary teeth: a clinical study. Journal American Dental Association 1884; **108**: 775–778.

Hobson P. Pulp treatment of deciduous teeth. Part 2: clinical investigation. British Dental Journal 1970; **128**: 275–283.

Holan G, Fuks AB. A comparison of pulpectomies using ZOE and KRI paste in primary molars: a retrospective study. Pediatric Dentistry 1993; **15**: 403–407.

Holan G, Eidelman E, Fuks AB. Long-term evaluation of pulpotomy in primary molars using mineral trioxide aggregate or formocresol. Pediatric Dentistry 2005; **27**: 129–136.

Hunter ML, Hunter B. Vital pulpotomy in the primary dentition: attitudes and practices of Specialists in paediatric dentistry practising in the United Kingdom. International Journal of Paediatric Dentistry 2003; **13**: 246–250.

Ibrecevic H, AL-Jame Q. Ferric sulfate as pulpotomy agent in primary teeth: twenty-month clinical follow-up. Journal of Clinical Pediatric Dentistry 2000; **24**: 269–272.

International Agency for Research on Cancer. IARC classifies formaldehyde as carcinogenic to humans. Press release no. 153, June 2004. http://www.iarc.fr/pageroot/PRELEASES/pr153a.html

Kopel HM. Considerations for the direct pulp capping in primary teeth: a review of the literature. ASDC Journal of Dentistry for Children 1992; **59**: 141–149.

Langeland K, Langeland LK, Anderson DM. Corticosteroids in dentistry. International Dental Journal 1977; **27**: 217–251.

Lee SJ, Monsef M, Torabinejad M. Sealing ability of a mineral trioxide aggregate for repair of lateral root perforations. Journal of Endodontics 1993; **19**: 541–544.

Llewleyn DR. UK National Clinical Guidelines in Paediatric Dentistry. The pulp treatment of the primary dentition. International Journal of Paediatric Dentistry 2000; **10**: 248–252.

Loh A, O'Hoy P, Tran X, Charles R, Hughes A, Kubo K, Messer LB. Evidence-based assessment: evaluation of the formocresol versus ferric sulfate primary molar pulpotomy. Pediatric Dentistry 2004; **26**: 401–409.

Massara MLA, Alves JB, Brandão PRG. Atraumatic restorative treatment: clinical, ultrastructural and chemical analysis. Caries Research 2002; **36**: 430–436.

Mortazavi M, Mesbahi M. Comparison of zinc oxide and eugenol and Vitapex for root canal treatment of necrotic primary teeth. International Journal of Paediatric Dentistry 2004; **14**: 417–424.

Nadin G, Goel BR, Yeung CA, Glenny AM. The Cochrane Database of Systematic Reviews: pulp treatment for extensive decay in primary teeth. The Cochrane Library Volume **3**, 2003.

National Institute for Occupational Safety and Health. Current Intelligence Bulletin 34. Formaldehyde: evidence of carcinogenicity. April 15, 1981http://www.cdc.gov.niosh/81111_34.html

Papagiannoulis L. Clinical studies on ferric sulfate as a pulpotomy medicament in primary teeth. European Journal of Paediatric Dentistry 2002; **3**: 126.

Pitts NB, Boyles J, Nugent ZY, Thomas N, Pine CM. The dental caries experience of 5-year-old children in England and Wales (2003/4) and in Scotland (2002/3). Surveys co-ordinated by the British Association for the Study of Community Dentistry. Community Dental Health 2005; 46–56.

Rivera N, Reyes E, Mazzaoui S, Morón A. Pulpal therapy for primary teeth: formocresol vs electrosurgery: a clinical study. ASDC Journal of Dentistry for Children 2003; **70**: 71–73.

Rock WP. UK National Clinical Guidelines in Paediatric Dentistry. Extraction of primary teeth – balance and compensation. International Journal of Paediatric Dentistry 2002; **12**: 151–153.

Rodd HD, Boissonade FM. Innervation density of human tooth pulp: a comparative study. Journal of Dental Research 2001; **80**: 389–393.

Rodd HD, Boissonade FM. Comparative immunohistochemical analysis of the peptidergic innervation of human primary and permanent tooth pulp. Archives of Oral Biology 2002; **47**: 375–385.

Rodd HD, Boissonade FM. Vascular status in human primary and permanent teeth in health and disease. European Journal of Oral Sciences 2005; **113**: 128–134.

Savage NW, Adkins KF, Weir AV, Grundy GE. An histological study of cystic lesions following pulp therapy in deciduous molars. Journal of Oral Pathology 1986; **15**: 209–212.

Sazak H, Gunday M, Alatli C. Effect of calcium hydroxide and combinations of ledermix and calcium hydroxide on inflamed pulp in dog teeth. Journal of Endodontics 1996; **22**: 447–449.

Schroder U. Effect of an extra-pulpal blood clot on healing following experimental pulpotomy and capping with calcium hydroxide. Odontologist Revy 1973: **24**: 257–268.

Seltzer S, Bender IB. Pulp reaction to operative procedures. In: The Dental Pulp. 3rd edn. Philadelphia: Lippincott,1984.

Smith NL, Seale NS, Nunn ME. Ferric sulfate pulpotomy in primary molars: a retrospective study. Pediatric Dentistry 2000; **22**: 192–199.

Srinivasan V, Patchett CL, Waterhouse PJ. Is there life after Buckley's Formocresol? Part I: a narrative review of alternative interventions and materials. International Journal of Paediatric Dentistry 2006; **16**: 117–127.

Starkey PE. Methods of preserving primary teeth which have exposed pulps. ASDC Journal of Dentistry for Children 1963; **30**: 219–224.

Swenberg JA, Kerns WD, Mitchell RI, Gralla EJ, Pavkov KL. Induction of squamous cell carcinomas of the rat nasal cavity by inhalation exposure to formaldehyde vapour. Cancer Research 1980; **40**: 3398–3402.

Takiguchi M, Fujiwara T, Sobue S, Ooshima T. Radicular cyst associated with a primary molar following pulp therapy: a case report. International Journal of Paediatric Dentistry 2001; **11**: 452–455.

Takushige T, Cruz EV, Asgor Moral A, Hoshino E. Endodontic treatment of primary teeth using a combination of antibacterial drugs. International Endodontic Journal 2004; **37**: 132–138.

Vij R, Coll JA, Shelton P, Farooq NS. Caries control and other variables associated with the success of primary molar vital pulp therapy. Pediatric Dentistry 2004; **26**: 214–220.

Waterhouse PJ. Formocresol and alternative primary molar pulpotomy medicaments: a review. Endodontics and Dental Traumatology 1995; **11**: 157–162.

Waterhouse PJ. Pulp therapy in the primary dentition. In: Paediatric Cariology. Eds Deery C, Hosey MT, Waterhouse PJ. London: Quintessence Publishing Co. Ltd, 2004: 99–117.

Waterhouse PJ, Nunn JH, Whitworth JM. An investigation of the relative efficacy of Buckley's formocresol and calcium hydroxide in primary molar vital pulp therapy. British Dental Journal 2000; **188**: 32–36.

Waterhouse PJ, Nunn JH, Whitworth JM. Prostaglandin E2 and treatment outcomes in pulp therapy of primary molars with carious exposures. International Journal of Paediatric Dentistry 2002; **12**: 116–123.