Chapter 2.6

ENDODONTIC MATERIALS

INTRODUCTION

Endodontics is concerned with the morphology, physiology and pathology of the human dental pulp and periradicular tissues. Endodontic treatment is aimed at saving the tooth when injury to the pulp and associated periradicular tissues has occurred. Treatments involving the use of dental materials include capping of an exposed vital pulp, sealing of the root canal space when the pulp has had to be removed and, in the case of badly broken down teeth, reconstruction with endodontic post and core systems (Figure 2.6.1).

VITAL PULP CAPPING

Two main causes of pulpal exposure are:
- dental decay and tooth wear
- accidental exposure during operative procedures or due to trauma.

In each of the above instances remedial treatment is necessary to save the tooth. The nature of this treatment depends upon which of the above causes of pulpal injury applies.

Indirect Pulp Capping

Sir John Tomes stated in 1859 that ‘It is better that a layer of discolored dentine be allowed to remain for the protection of the pulp rather than run the risk of sacrificing the tooth.’ He had observed that discolored and demineralised dentine could be left behind in deep cavities of the tooth before restoration, often with highly satisfactory results. This is especially applicable if micro-exposures of the pulp are suspected. The removal of this dentine may lead to exposure of the pulp, thus impairing its prognosis. It has been shown that demineralised dentine, if it is free of bacteria, will remineralise once the source of the infection has been eliminated. The diagnosis of the presence of demineralised dentine that is caries-free can be assisted by using a caries-disclosing solution. The placement of a suitable material directly on this demineralised dentine is commonly called indirect pulp capping (IPC) and it has to be said that there is as yet no clear consensus for the acceptance of this clinical procedure. IPC has been defined as the steps undertaken to protect a vital tooth where removal of all affected tissues would result in a pulpal exposure. In this context a non-exposed pulp is one that exhibits no signs of haemorrhage at or near the pulp chamber. When carrying out such a procedure it is vitally important that the infection is removed and is not allowed to recur. This can be achieved with the placement of an antibacterial liner such as calcium hydroxide or zinc oxide-eugenol cement, which is aimed at stimulating secondary dentine formation. Of course resin composites should not be placed directly on eugenol-based liners because they interfere with the polymerisation of the resin.

With the advent of adhesive dental materials, another possible restorative option is the placement of calcium hydroxide cement followed by an adhesive liner such as glass–ionomer or resin-modified glass–ionomer cement. Yet, another option is the use of resin composites in conjunction with a dentine-bonding agent. The aim is to provide a combination of an antibacterial barrier and an adhesive seal against the further ingress of bacteria,
thus removing the pulpal antagonist and allowing the pulp to heal. When calcium hydroxide is used in this way, it should be applied sparingly so as to ensure as much dentine is available for further bonding with the glass–ionomer cement/resin-modified glass–ionomer cement or dentine-bonded resin composite.

More recently an adhesive approach involving the direct application of a dentine-bonding agent has been proposed. This is aimed at sealing the remaining dentine by the creation of the hybrid zone, thus preventing immediate post-operative sensitivity and protecting the tooth from the ingress of bacteria. There are those who have serious reservations about acid etching dentine so close to the pulp, but as Figure 2.6.2 shows, the demineralisation of the dentine by the penetration of acid is only a matter of a few micrometres. Further evidence exists to support the position that acid etching of dentine will not kill the underlying pulp. With regard to the stimulation of secondary dentine, more evidence has been gathered to suggest that this is not a feature unique to calcium-hydroxide cement.

**Direct Pulp Capping**

Direct pulp capping can be described as the dressing of an exposed pulp with the objective of maintaining pulp vitality. If a pulpal exposure occurs as a consequence of tooth preparation or trauma, it is important that steps are taken to avoid bacterial contamination. If one can be sure that this is the case then the procedure of direct pulp capping carries a good prognosis for saving the pulp, although views vary the general consensus is that calcium-hydroxide cement is the choice of pulp-capping material in such situations.

Nevertheless, many clinicians believe that the long-term success rate with root-canal therapy does not warrant the treatment of traumatic pulp exposures with the more unpredictable pulp-capping procedures, especially as unsuccessful pulp capping may lead to resorption, calcification, pulpite, pulp necrosis or periapical involvement. However, the advantages of a successful pulp-capping procedure are that young vital teeth have an opportunity to continue to develop and the tooth-weakening effects of root-canal treatment are avoided.

If direct pulp capping as a clinical procedure is controversial, then so is the choice of materials for pulp capping. A pulp-capping material can be considered to behave as a wound dressing for the exposed pulp. Such a material can either passively wall off the pulp from the outside environment so as to prevent bacterial invasion and/or can induce some change in the pulp.

**CLINICAL SIGNIFICANCE**

The important points to appreciate are that many dental materials:
- are biologically compatible with the pulp for indirect pulp capping as long as there are no bacteria present and coronal microleakage is prevented
- will stimulate the formation of reparative dentine.
There is evidence to suggest that the pulp has the capacity to wall itself off by forming a connective-tissue barrier that eventually changes into hard tissue. The induction of hard-tissue formation needs to be preceded by a low-grade irritation that results in superficial coagulation necrosis. On this basis, a pulp-capping material must:

- have a superficial effect on the pulp tissue, thereby inducing a biological encapsulation process that results in hard-tissue formation
- cause no adverse effects, whether systemically or locally, such that the pulp is kept alive
- protect the pulp from the coronal ingress of bacteria.

In other words, a pulp-capping material needs to be able to interact with the pulp to initiate hard-tissue formation, and, once this process has been triggered, should adopt a passive role.

If the pulp is exposed due to the presence of caries, the procedure for pulp capping is contraindicated; the infiltration of bacteria that will have occurred into the pulp cannot be reversed, and the only solution is a full pulpectomy.

**Pulp-Capping Materials**

Until recently, the only material that appeared to satisfy the requirements for pulp capping was calcium-hydroxide cement, which was first used for this purpose in the 1930s. However, their dominant position as the preferred pulp-capping material is now being challenged by the dentine-bonding agents.

**Calcium-Hydroxide Cements**

The first use of Ca(OH)₂ was in the form of a slurry, consisting of no more than a mixture of calcium hydroxide in water. This was changed to a paste using methyl cellulose, being somewhat easier to handle. In the early 1960s the hard-setting calcium hydroxide cements were introduced, where the calcium hydroxide reacts with a salicylate ester chelating agent in the presence of a toluene sulfonamide plasticiser (see Chapter 2.4). The hard-setting cements are either two-paste systems or are single-paste systems consisting of calcium-hydroxide-filled dimethacrylates, polymerised by light.

The problem with the non-setting versions is that these will gradually dissolve and disappear from underneath the restoration, which can undermine the restoration’s function. The hard-setting versions are therefore generally preferred as these are less soluble. The difficulty for the manufacturer is to achieve a balance between a material that is sufficiently soluble to be therapeutic and not so soluble as to dissolve away, although it is arguable if the pulp-capping material needs to release anything to stimulate dentine-bridge formation.

When the paste is brought in contact with the pulp it causes a layer of necrosis of some 1.0–1.5 mm thick, that eventually develops into a calcified layer. Experiments using radioactive calcium in the paste have shown that the calcium salts necessary for mineralisation of the bridge are not derived from the cement, but are instead supplied by the tissue fluids of the pulp. Once the bridge has become dentine-like in appearance, and the pulp has been shut off from the source of the irritation, the hard-tissue formation ceases. It is believed that the high pH of the calcium-hydroxide cement is responsible for this type of pulpal response, and that this is also closely associated with its antibacterial properties.

**Dentine-Bonding Agents**

The use of dentine-bonding agents is even more controversial than the use of calcium hydroxide as a direct pulp-capping agent, but is an area being extensively researched. As stated by Stanley (1998), the research data on pulp capping are, at times, inadequate, confusing, misleading or even incorrect and diminish the confidence of practitioners in performing pulp capping. At best the situation is confusing and more research is needed to make any definitive statement. Haemostasis seems to be essential and for this cleaning with a dilute solution of sodium hypochlorite (1.0 % or less) has been recommended. If bleeding cannot be controlled within a matter of a minute, endodontic treatment is indicated.

What continues to remain controversial is the practice of total-etch direct bonding with dentine-bonding agents and more research needs to be focussed on this area. Some successes have been claimed with direct pulp capping with dentine-bonding agents when the acid etch step is omitted or with bonding systems not requiring a separate acid-etch step, such as the self-etching primers, despite the observation that phosphoric acid can act as an effective haemostatic agent. Hence, the results obtained with one dentine-bonding agent may be different from those obtained with another.
dentine-bonding agent such that clinical experience cannot be extrapolated from one to the other. It is, therefore, not surprising that most general dental practitioners continue to use a minimal quantity of calcium hydroxide, before placing a dentine-bonding agent.

**Failure after Direct Pulp Capping**

Failure after direct pulp capping can be due to three reasons:

1. **Chronically inflamed pulp.** There is no healing effect on inflamed pulp, and, in such situations, a full pulpectomy is indicated.
2. **Extra-pulpal blood clot.** Such a blood clot prevents contact between the healthy pulpal tissue and the cement and interferes with the wound-healing process.
3. **Restoration failure.** If the restoration fails to provide a bacterial seal then coronal ingress of bacteria can give rise to failure.

It is important to distinguish the last of these failures from the others, as it is not strictly speaking a failure of pulp capping.

**Clinical Significance**

The long-term success of direct pulp capping depends not only on the reactions induced local to the pulp by the pulp-capping material, but is also crucially dependent on the practitioner being able to make certain that microleakage will not occur and the marginal seal is maintained.

**Root Canal Filling Materials**

The objectives of modern non-surgical endodontic treatment are:

- **To provide a clean canal.** The aim is to produce a reduction of bacteria to a non-pathogenic level.
- **To provide an ‘apical seal’.** This prevents the ingress of fluids which will provide nutrients for canal bacteria and also prevents irritants leaving the canal and entering the periapical tissues.
- **To provide a ‘coronal seal’.** This prevents recontamination due to the ingress of oral microorganisms.

A wide variety of materials have been used in an attempt to produce an impervious seal of the tooth root apex. The most widely used root-canal sealing materials are a combination of root obturating points and canal-sealer cements.

**Obturating Points**

**Gutta Percha**

Gutta percha is a rubber that is tapped from the Taban tree. It was introduced into the UK in 1843 and has been used in endodontics for over 100 years. Rubbers are polymers of isoprene (2-methyl-1,3-butadiene) and isoprene is a geometric isomer, which means that it can have different structural arrangements despite having the same composition as depicted in Figure 2.6.3. When the CH$_3$ group and the H atom are positioned on the same side of the isoprene mer, this is termed a *cis* structure and the resulting polymer, cis-isoprene, is known as natural rubber. When the CH$_3$ group and the H atom sit on opposite sides of the isoprene mer, this is termed the trans structure and trans-isoprene polymer is commonly referred to as gutta percha (Figure 2.6.4). The
Effect on the properties of these different configurations of the polymer is quite profound. In the cis form, the hydrogen atom and methyl group prevent close packing such that the natural rubber is amorphous and consequently soft and highly flexible, whereas the gutta percha crystallises, usually about 60% crystalline, forming a hard rigid polymer.

The natural rubbers are soft and tacky unless they are hardened by vulcanisation, a process discovered by Charles Goodyear in 1839 (see Chapter 1.1). Vulcanisation involves heating the polymer with a few percent by weight of sulphur. The hardening occurs because sulphur bridges or cross-links form between the polymer chains, preventing the polymer molecules from slipping over one another. This cross-linked rubber is used to produce rubber dam and rubber gloves.

Gutta percha is a thermoplastic material and softens at 60–65°C and will melt at about 100°C, so it cannot be heat-sterilised. If necessary, disinfection can be carried out in a solution of sodium hypochlorite (5%). The use of solvents such as acetone or alcohol should be avoided, as these are absorbed by the gutta percha, causing it to swell. Eventually, the gutta percha will return to its unswollen state, thus compromising the apical seal. On exposure to light, gutta percha oxidises and becomes brittle. It is therefore important to check that the points have retained their flexibility before using them.

The gutta percha is able to take up two distinct conformations. At high temperature, the gutta percha chains take on an extended conformation, which can be preserved if cooled rapidly so that it forms the crystalline β-phase, whereas when the gutta percha is cooled more slowly, the denser α-phase is formed (Figure 2.6.4). The α-phase gutta percha has better thermoplastic characteristics and is therefore preferred for use in hot gutta percha.
application systems, where heat-softened gutta percha is injected into the root-canal filling. This technique was first developed by Johnson in 1978 and further improvements of the original technique include the use of plastic carriers (Thermofil) and injection guns (Obtura) for the delivery of softened gutta percha. However, in the presence of a patent apical foramen, there may be a predisposition for extrusion of filling material beyond the apex.

An alternative approach is to dissolve the gutta percha in a chemical solvent such as chloroform or xylene. This softens the gutta percha and allows it to be adapted closely to the canal wall and duplicate the intricate canal morphology. However, as the solvent is lost, so the dimensional stability may be compromised and concerns have been expressed regarding the possible cytotoxic effects of using these solvents.

One of the main uses is the gutta percha point, which is softened and compacted by warm vertical and lateral condensation. The composition of commercially available gutta percha obturating points will vary from product to product, but typical values are shown in Table 2.6.1. The additional ingredients are added to overcome the inherent brittleness of the rubber and to make it radiopaque.

**Metal Points**

Metals, including gold, tin, lead, copper amalgam and silver, have long been used as root-canal filling materials. Silver points were at one time extensively used because of their bactericidal effect. Silver is a more rigid and unyielding material than gutta percha and was used when access and instrumentation was difficult due to a small cross-section or awkward anatomy. Unfortunately, the rigidity of silver made it impossible to adapt it closely to the canal wall and greater reliance had to be placed on the cements used to provide the seal. Other disadvantages with silver points were that they tended to corrode, which could give rise to apical discoloration of the soft tissues, and they were problematic to remove. Corrosion can be limited by sealing the entire point within the root canal, such that it is totally surrounded by the sealer cement. However, acrylic and titanium points are now available as alternatives to silver points in order to avoid the problems of corrosion and silver points are perhaps now only of historical interest.

**ROOT CANAL SEALER CEMENTS**

The ideal properties of a root canal sealer are that it should:

- be easy to use
- be free of air bubbles and homogeneous when mixed
- flow to a thin film thickness
- be insoluble
- adapt well to the canal wall and the obturating point
- be radiopaque
- be biocompatible
- be bacteriocidal, or at least bacteriostatic
- be easy to remove in case of failure.

It is well accepted that the sealing properties of a conventionally applied and laterally condensed gutta percha is such that it is essential that they are used in conjunction with a root-canal sealer cement. The function of the cement is to fill the spaces between the obturating point and the wall of the root canal, producing an antibacterial seal. It also lubricates the gutta percha points during compaction and will fill canal irregularities and lateral canals.

Conversely, the use of root-canal cements without obturating points is also contraindicated. When used in bulk, the cements are either too soluble or shrink excessively on setting. Additionally, it is difficult to gauge when, or if, the canal is adequately filled, and there is a danger that the cement may pass beyond the root apex into the surrounding tissues.

It is interesting to note that a similar approach with root-canal sealers has been adopted as with cavity liners. It is now accepted that the root-canal sealer cement is unable to provide an impervious seal and most of the attention has been focussed on incorporating antibacterial properties, with the emphasis on providing an anti-bacterial seal.

A wide variety of materials are used as root-canal sealers and these include:

<table>
<thead>
<tr>
<th>Table 2.6.1 Composition of gutta percha points</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Constituent</strong></td>
</tr>
<tr>
<td>Gutta percha</td>
</tr>
<tr>
<td>Zinc oxide</td>
</tr>
<tr>
<td>Heavy metal salts</td>
</tr>
<tr>
<td>Wax or resin</td>
</tr>
</tbody>
</table>
zinc oxide–eugenol cements (e.g. Tubliseal, Kerr)
resins (e.g. AH Plus, Dentsply; Diaket, 3M/ESPE)
calcium-hydroxide-containing cements (e.g. Apexit, Ivoclar; Sealapex, Kerr)
glass–ionomer cements (e.g. Ketac Endo, 3M/ESPE; Endion, Voco)
polydimethyl siloxanes (e.g. RSA RoekoSeal, Roeko)
mineral trioxide aggregate (e.g. Pro-Root MTA, Dentsply).

First, the composition of the most widely used sealer, zinc oxide–eugenol cements, will be described. Then, the characteristics which make them suitable as sealers will be discussed, and finally, the clinical data on their performance will be assessed.

**Zinc Oxide–Eugenol-Based Cements**

There are many cements based on zinc oxide, used with eugenol, to which are added a variety of other substances to modify them for use as root-canal sealers (see Chapter 2.4). There are three major reasons for the additives in root canal sealers:

- to impart bacteriocidal properties
- to increase their radiopacity
- to improve the adhesion to the canal wall.

As with zinc oxide–eugenol cements used for cavity liners and temporary fillings, some of the sealers consist of a powder, which is mixed with a liquid. The complete list of ingredients of one widely used material (based on a formulation originally proposed by Rickert in 1931) is presented in Table 2.6.2. The powder is predominantly zinc oxide, to which silver is added to increase the radiopacity. The resin acts as a plasticiser and the iodide as an antiseptic agent.

The problem with this formulation is that the silver is prone to causing discoloration of the dentine. This is problematical particularly in the coronal access cavity, and affects the appearance of the tooth. Formulations such as Grossman’s Sealer (Table 2.6.3) have replaced the silver with barium or bismuth compounds.

The particle size of the above preparations is fairly large and tends to produce a gritty texture to the resultant mix unless it is thoroughly spatulated. To overcome this, paste–paste systems have been developed and have become very popular. The typical constituents of such a root canal sealer are presented in Table 2.6.4.

| Table 2.6.2 Composition of a zinc-oxide–eugenol cement based on Rickert’s formulation |
|---------------------------------|-----|--------------|
| Powder %                    | Liquid %                  |
| Zinc oxide                  | 34–41 | Oil of cloves 78–80 |
| Silver                      | 25–30 | Canada balsam  20–22  |
| Oleoresin                    | 16–30 | Dithymoliodide 11–13  |

| Table 2.6.3 Composition of Grossman’s Sealer (Grossman) |
|---------------------------------|-----|--------------|
| Powder %                    | Liquid %                  |
| Zinc oxide                  | 42 | Eugenol 100 |
| Staybelite resin             | 27 |  |
| Bismuth subcarbonate         | 15 |  |
| Barium sulphate              | 15 |  |
| Sodium borate                | 1  |  |

| Table 2.6.4 Composition of Tubliseal (Kerr Mf. Co., USA) |
|---------------------------------|-----|--------------|
| Base %                     | Catalyst |
| Zinc oxide                  | 57–59 | Eugenol |
| Oleo resin                  | 18–21 | Polymerised resin |
| Bismuth trioxide            | 7.5  | Annidalin |
| Thymol iodide               | 3–5  |  |
| Oils and waxes              | 10   |  |

**Resins**

The attraction of resin systems is that these materials can readily be formulated in such a way that they have a rapid setting time and yet maintain a sufficiently long working time. Also, these products do not contain any coarse powders so they have a very smooth texture.

There are two resin systems that have been around sufficiently long for some clinical data to have been gathered on them. These are, an epoxy-amine resin (AH Plus, De Trey, Germany) and a polyvinyl resin (DIAKET, 3M/ESPE, Seefeld, Germany). Both have very complex formulations and the composition of AH Plus is shown in Table 2.6.5. The resin sets by an addition polymerisation reaction after the two pastes are mixed. The diepoxide, a diglycidyl ether of bisphenol-A, and an amine, either 1-adamantane amine or N,N'-dibenzyl-5-oxannonandiamine-1,9, react to form oligomers with epoxy and amino end...
groups, which can then react with other monomers or oligomers, as shown in a simplified form in Figure 2.6.5. This produces a highly flexible thermoplastic polymer of high dimensional stability, although still subject to polymerisation shrinkage. The addition polymerisation reaction takes several hours and thus provides a long working time. The radiopaque fillers ensure that the material has a high radiopacity, even when applied in thin layers. Viscosity is controlled by the amount (>76% by weight) and type of filler. Filler particle size averages out at less than 10 μm to ensure a thin film thickness and provide a smooth consistency. The main problem with these resins is the amount of shrinkage that takes place on setting, which can compromise the apical seal.

Calcium-Hydroxide-Containing Cements

Calcium-hydroxide-containing cements are presented in the form of a base paste and catalyst paste, which are mixed in equal amounts. They contain a resin similar to those used in the two-paste resin composites, to which is added calcium hydroxide as a filler in place of the more usual glass fillers. The composition of one of these materials is presented in Table 2.6.6. As yet, little is known about the clinical performance of these materials. These materials have long working times and a high pH, which creates a highly alkaline environment, where most bacteria will be killed. Biocompatibility is excellent with the formation of a cementum over the apical foramen. One drawback is their high solubility, which has raised concerns about possible coronal or apical microleakage after a time.

Glass–Ionomer Cements

The glass–ionomer cements consist of a fluoroalumino-silicate glass, which is reacted with a polycarboxylic acid. Since glass–ionomer cements show low shrinkage on setting and possess the virtually unique ability to bond directly to dentine and enamel, these materials should make good root-canal sealers. Surprisingly, it wasn’t until the early 1990s that a glass–ionomer cement was developed specifically as a root-canal sealant. The glass–ionomer cements used for restorative and lining purposes needed to be modified to deal with a range of problems. These included: too short a working time, difficulty in transporting the material to the

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### Table 2.6.5 Composition of AH Plus (Dentsply De Trey GmbH, Germany)

<table>
<thead>
<tr>
<th>Paste A</th>
<th>Paste B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epoxy resin</td>
<td>1-adamantane amine</td>
</tr>
<tr>
<td>Calcium tungstate</td>
<td>N,N’-Dibenzyl-5-oxanonane-diamine-1,9</td>
</tr>
<tr>
<td>Zirconium oxide</td>
<td>TCD-diamine</td>
</tr>
<tr>
<td>Aerosil</td>
<td>Calcium tungstate</td>
</tr>
<tr>
<td>Iron oxide</td>
<td>Zirconium oxide</td>
</tr>
<tr>
<td></td>
<td>Aerosil</td>
</tr>
<tr>
<td></td>
<td>Silicone oil</td>
</tr>
</tbody>
</table>

### Table 2.6.6 Composition of Sealapex (Kerr Mf. Co., USA)

<table>
<thead>
<tr>
<th>Base paste</th>
<th>%</th>
<th>Catalyst paste</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium hydroxide</td>
<td>46</td>
<td>Barium sulphate</td>
<td>39</td>
</tr>
<tr>
<td>Sulfonamide</td>
<td>38</td>
<td>Zinc oxide</td>
<td>12</td>
</tr>
<tr>
<td>Zinc oxide</td>
<td>12</td>
<td>Isobutyl salicylate</td>
<td>17</td>
</tr>
<tr>
<td>Zinc stearate</td>
<td>2</td>
<td>Colloidal silica</td>
<td>17</td>
</tr>
<tr>
<td>Colloidal silica</td>
<td>2</td>
<td>Titanium dioxide</td>
<td>7</td>
</tr>
<tr>
<td>Colloidal silica</td>
<td>2</td>
<td>Iron oxide</td>
<td>&lt;1</td>
</tr>
</tbody>
</table>

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Figure 2.6.5 The setting reaction of AH Plus, which is based on an epoxide-amine addition reaction.
root canal, adaptation to the root canal wall, lack of low film thickness, lack of radiopacity and questions about the biocompatibility when in contact with the apical tissues. These problems have now been largely overcome by incorporating an X-ray contrasting agent and reducing the glass particle size to less than 25 μm. Some promising results have been obtained with glass–ionomer-cement sealers, although working times still tend to be short and retreatment is a problem as the material sets very hard compared to the other root-canal sealers.

**Polydimethyl Siloxanes**

This root canal sealer is essentially a variant on the addition-cured polyvinylsiloxane impression materials, consisting of a polydimethylsiloxane, silicone oil, paraffin-base oil, a Pt catalyst and zirconium dioxide (see Chapter 2.7 for details of the setting chemistry). The delivery system ensures a homogeneous mix, free of air bubbles and the rheology can be carefully controlled by the addition of the appropriate amount of filler. The small filler particle size ensures that this material has excellent flow properties and can achieve a film thickness of 5 μm, which allows the sealer to flow into tiny crevices and tubules. As with the impression materials, the root canal sealer is insoluble, dimensionally stable and has excellent biocompatibility. One concern is that this root-canal sealer has neither the ability to bond to dentine, nor any antibacterial properties. It relies for its seal on the ability to adapt to the root canal wall and according to the manufacturer undergoes a slight expansion (0.2%) on setting. Further studies, especially clinical data, are needed to confirm the suitability of this product as a root-canal sealer.

**Metal Trioxide Aggregate**

Metal trioxide aggregate is a cement composed of tricalcium silicate, dicalcium silicate, tricalcium aluminate, tetracalcium aluminoferrite, calcium sulphate and bismuth oxide. Its composition is not unlike that of Portland cement except for the addition of bismuth oxide. The latter is added in order to improve its radiopacity.

Metal trioxide aggregate has a very alkaline pH (~12.5) and has biological and histological properties similar to those of calcium-hydroxide cement. It has been shown that metal trioxide aggregate can induce bone deposition with a minimal inflammatory response as it is less cytotoxic than reinforced zinc oxide–eugenol cements.

The material is mixed with sterile water to provide a grainy, sandy mixture and then can be gently packed into the desired area. The material is difficult to handle and the powder:liquid ratio (3:1) is critical if one is to achieve appropriate hydration of the powder. Metal trioxide aggregate requires moisture to set, such that absolute dryness is not only unnecessary but is contraindicated. On occasion it may be necessary to place a moist cotton pellet directly in contact with the material in order to allow proper setting; however, excessive moisture softens the material. It takes an average of 4 hours for the material to completely solidify and once the cement has set it has a compressive strength comparable to that of reinforced zinc oxide–eugenol cement. It should be noted that a low pH environment can prevent the material from setting.

Metal trioxide aggregate has been recommended for use as a root-end-filling material, a retrograde root-filling material, to seal perforations or open apices, or to cap vital pulps.

**CLINICAL ASPECTS OF ROOT CANAL MATERIALS**

Root-canal materials are in contact with living biological tissue that is not protected by any epithelial layer; therefore, their biocompatibility is of considerable importance. Their physical properties, relevant to the production of an apical seal, are also a major concern.

**Biocompatibility**

In general, it is assumed that for a material to be biologically acceptable it must be as inert as possible. However, this is not always the case. In a sense, what is really desired is an interaction between the material and the biological environment that is beneficial to the biological environment and has no adverse effect on the material. This is very different from complete lack of interaction in the case of an inert material. The concern is over the form of the interaction.

When a sealer is placed at the apex of a root canal it will be in contact with vital tissue. It is important that the material does not elicit an inflammatory response in the tissues as this may induce
irritation, pain or tissue necrosis. All of these responses are likely to lead to the loss of the tooth, which is just the opposite of the intended outcome. A possibly beneficial response would be the formation of an intermediate layer of hard tissue that not only isolates the foreign material from the living tissue, but also helps to improve the quality of the apical seal.

A perennial problem in endodontic treatment is the likelihood of recurrent infection due to the presence of bacteria at the apex of the tooth. Thus, another feature one seeks in a root canal sealer is the ability to destroy bacteria.

As might be imagined, it is difficult to reconcile these two requirements as they would require a high degree of selectivity in the biological response. In general, materials that show antibacterial properties also induce some inflammatory response in the local tissues, while those that do not elic it an inflammatory response are, at best, bacteriostatic.

If it is accepted that a perfect seal cannot be achieved, the materials used must have sufficient antibacterial activity to prevent bacteria from infiltrating the canal space and proliferating. However, the antibacterial property of a material should not be achieved at the expense of its biocompatibility.

Gutta percha is a highly biocompatible material, having such a low cytotoxicity that it is the cements that are used with it that will determine the tissue response.

The zinc oxide–eugenol-based cements are all inclined to induce some inflammatory reaction in the tissues, probably due to the presence of free eugenol. It is therefore important that measures are taken to ensure that the cement does not leak beyond the apex and into the vital tissues. Some formulations must be avoided because they contain paraformaldehyde, which may cause a severe inflammatory response, leading to tissue necrosis and bone resorption. Some cements have an incorporated steroid, and, again, their use is contraindicated.

The resin systems should have comparatively excellent biocompatibility, as none of them contains the eugenol that contributes to the poor biocompatibility of the zinc oxide cements. Resins are known to be slightly toxic during the setting period but that once it has fully set, any inflammation rapidly recedes. The moderate cytotoxic response of freshly prepared AH26 may be associated with the release of formaldehyde, which is produced as a by-product of the setting process. Since AH26 takes some time to set, a certain degree of sensitivity may be associated with the use of this sealer. AH Plus has been shown to release only a tiny amount of formaldehyde (3.9 ppm) as compared with AH26 (1347 ppm). Nevertheless AH26 has been shown to be cytotoxic, although this is much reduced after the material has set. In comparison, Diaket retains a degree of cytotoxicity even after it has set.

For the calcium-hydroxide-containing resins it is claimed that, in addition to the excellent biocompatibility, the material promotes cementum formation, which is similar to that observed for the pulp-capping agents based on calcium hydroxide.

### Sealing Properties

One of the difficulties in interpreting the information available on sealing properties is the lack of any standardised approach to the methods of measurement adopted, as this limits the value of the data available. This is particularly so for studies of the sealing properties, whether in vivo or in vitro, where so many methods have been used that direct comparison is unreliable, and only a general assessment is possible.

First, it is noticeable that there is no immediate distinction between the zinc oxide–eugenol cements and the resin-based materials. It would seem that some zinc oxide–eugenol cements are better than one or other resin system and that others are worse.

However, it should be appreciated that so much depends on the technique adopted that an acceptable result can most probably be obtained with any of them. As already noted, it is probably more important that an antibacterial seal is achieved than a physical seal, although both would be desirable. A physical seal by itself may not be good enough if the sealant does not provide an antibacterial barrier.

### Physical Properties

Since the results of endodontic treatment are so dependent upon the operator, it is important to choose a material which has the handling characteristics that most suit the particular individual. The working and setting times and flows of the cements determine their handling characteristics, while the film thickness, the solubility and the dimensional stability are important factors in determining their sealing ability.
Rickert’s cement has a working time of some 15 minutes; it flows readily, but is inclined to have a thick film width due to the gritty nature of the powder. Grossman’s sealer has a working time of 1 hour and also shows good flow; its solubility is lower than that of Rickert’s cement. Tubli-seal is a two-paste cement; it has a short working time (20 minutes), combined with good flow and a low film thickness.

The resin sealer Diaket has a very rapid set, and is sticky and viscous and difficult to manipulate. In comparison, AH Plus has a much longer working time, a better flow and lower film thickness. Once set, both of these materials are virtually insoluble.

The calcium-hydroxide-filled resins have good handling characteristics, but still require some clinical evaluation before they can be recommended for general use. The same applies to the glass–ionomer and the polyvinyl siloxane root-canal sealer.

**CLINICAL SIGNIFICANCE**

Despite the introduction of a wide variety of root-canal sealers, the preferred material among endodontists continues to be the zinc oxide–eugenol cement sealer.

**SUMMARY**

The ideal of a hermetic seal of the root apex has been abandoned in favour of an antibacterial seal for most of the root-canal sealers. Perhaps only the glass–ionomer cements, with their intrinsic dentine-bonding capability, can possibly achieve a hermetic seal. For the present, the view is that an antibacterial seal can be achieved only by the combined use of gutta percha obturating points and root-canal sealer cements. There are many cements to choose from and the paste–paste systems are the most popular.

Failure can be due to the presence of residual bacteria as a result of inadequate chemomechanical debridement, especially in inaccessible canals in multi-rooted teeth, and in unsealed lateral canals, or due to the coronal ingress of bacteria. With currently available materials, it should be possible to obtain an adequate antibacterial seal.

**POST AND CORE SYSTEMS**

Extensive loss of tooth structure often requires endodontic treatment and as a consequence little may be left of the tooth crown. It is generally believed that to rebuild such a tooth there is a need for some form of reinforcement for the core. The most commonly used methods for reinforcing badly broken down and endodontically treated teeth are pin-retained cores or post and core systems (Figure 2.6.6). However, with regard to post and core systems there has been passive acceptance of traditional concepts that have surprisingly little backing, and more and more the status quo is being challenged and some dentists are now asking if a post is really necessary. The factor that weakens the tooth is simply the extensive removal of tooth tissue. It is not a consequence of embrittlement of the dentine as was once thought, since the root dentine does not significantly change in properties. The fractures often associated with endodontically treated teeth are simply a consequence of the removal of tooth tissue, weakening the tooth structure such that it is no longer able to withstand the forces exerted on it. Although one will often see the post and core system referred to as a means of strengthening the tooth, this is possibly only the case when the post and core are effectively bonded to the tooth tissues such that the structural integrity of the tooth is improved. It is debatable how many, if any, of the current systems can claim to provide this benefit. Hence the function of a post and core system is not primarily to strengthen the tooth but to provide support for the retention
of crown or other coronal superstructure, when a significant amount of coronal tooth structure has been lost. If there is sufficient remaining coronal tooth structure, then there really is no need for a post and core buildup. However, if most of the supra-gingival tooth structure is missing, then a post and a core becomes an essential prerequisite to crown preparation for anterior teeth, while posteriorly it may still be possible to use a pin-retained core.

The desirable features of a post and core system are that:

- the system provides maximum retention with minimal removal of tooth tissue
- the core provides a means of transferring stress from the restoration to the post and tooth
- the post is able to transfer the stresses to the remaining tooth structure without creating high stresses that may otherwise cause the tooth to fracture
- the post is retrievable in the case of failure
- the post and core system is aesthetically compatible with the restoration.

**Types of Post Systems**

Posts are either prefabricated or cast. In the case of the prefabricated post, the core can be built up with one of a range of core materials (amalgam, composite, glass-ionomer cement, resin-modified glass-ionomer cement). For the cast post, it is usual to use a prefabricated plastic blank and the core can be incorporated with the blank such that the post and core is cast as a single unit. Whereas at one time a cast post and core would have been the system of choice, these days many dentists prefer some form of prefabricated post. The advantage is that the procedure is much quicker, simpler and cheaper than providing a cast system. The latter takes two appointments to complete and also requires the production of temporary restorations. However, cast post and core systems act as a single unit and can be cast with a ferrule (Figure 2.6.7), which supports the tooth against wedging forces and helps to prevent tooth fracture.

The types of prefabricated posts available are:

- metal posts
- fibre-reinforced resin posts
- ceramic posts.

**Prefabricated Posts**

**Metal Posts**

Metal prefabricated posts are made from stainless steel, nickel-chromium or titanium. The choice of these metals reflects the desire to use metals that have good corrosion resistance and have a high yield strength. The posts come in a wide variety of designs, which include:

- non-threaded parallel-sided posts (e.g. Para-Post, Whaledent)
- non-threaded tapered posts (e.g. Endo-Post, Kerr)
- threaded parallel-sided posts (e.g. Kurer Anchor System, Teledyne)
- threaded tapered posts (e.g. Dentatus Screw Post, Dentatus).

It is impossible in a textbook such as this to cover in detail all the different designs of post systems that are available. Briefly, the post should be as long as possible without infringing on the apical 4–5 mm of the root-canal seal. The post diameter should be as thin as possible to minimise removal of tooth tissue while also being sufficiently strong not to fracture itself. At the same time the post should be sufficiently stiff so as not to flex as this will compromise the marginal seal. Increasing the post diameter will weaken the tooth and make it more liable to fracture. Retentive features such as threads or...
surface roughening can help but it should be noted that threads can give rise to local stress concentrations, which can contribute to tooth fracture. In this context, self-threading posts have excellent retention but are also associated with a high incidence of tooth fracture. Tapered posts are the least retentive and the greater the taper, the greater the possibility of root fracture due to a wedging effect.

**Fibre-Reinforced Resin Posts**

Fibre-reinforced epoxy resin composite materials are increasingly finding a place in restorative dentistry and endodontics is no exception. The fibres are aligned in the long direction of the post, which provides strength and yet does not compromise the flexibility of the post. At present there are two types of fibre-reinforced resin post systems:

- carbon-fibre-reinforced posts (e.g. Composipost and Aestheti Post from RTD, Meylon, France; Carbonite from Harald Nordon sa, Montreux, Switzerland)
- glass-fibre-reinforced posts (e.g. Snowpost from Carbotech, Ganges, France; Parapost Fiber White from Coltene/Whaledent, New Jersey, USA; Aestheti Plus Post from RTD, Meylon, France; Glassix from Harald Nordon sa, Montreux, Switzerland).

The use of a resin matrix means that the post has the potential to be bonded to the remaining tooth structure and in turn the core can be bonded to the post. This, it is claimed, will improve the structural integrity of the tooth root and thus, unlike the metal posts, provide a stronger support structure for the crown with less chance of root fractures. This alters the requirements of the posts compared to metal posts, since the system acts as a single unit for supporting the crown. Whereas in the case of metal posts a high stiffness is important at preventing bending as noted earlier, in the case of fibre-reinforced resin composite posts, the aim is to produce a restoration that, being bonded, acts as a homogeneous unit. The way to achieve this is to use a material with an elastic modulus similar to that of dentine. This would allow a more even stress distribution and should reduce the incidence of tooth fractures.

The carbon-fibre-reinforced posts are black, unless specifically coated to mask the black colour as in the case of the Aestheti Post (RTD, Meylon, France). Glass-fibre-reinforced posts have the advantage that, being essentially white or white/translucent, they can produce superior aesthetic results when used in conjunction with all-ceramic restorations.

**Ceramic Posts**

From the point of view of aesthetics, ceramic posts would show considerable promise. Hence manufacturers have started recently to produce ceramic posts as an alternative to the white-fibre-reinforced posts. One of the materials that has become popular for such posts is zirconia because of its reputed high strength and toughness and white appearance. Current systems include the Cosmopost (Ivoclar-Vivadent, Liechtenstein), the Biopost (Incermed, Lausanne, Switzerland) and the Cerapost (Brassler, Lemgo, Germany). However, the chemical inertness of zirconia is a potential problem with regard to retention and these systems must rely on mechanical means of retention. Dislodgement of the posts can occur due to rotation of the crown resulting in torsional stresses. Zirconia posts have a lack of torsional resistance due to a lack of bonding, whereas the lack of torsional resistance in a fibre-reinforced post arises from the lack of stiffness of the post. As yet information in these post systems is still very scarce.

**CLINICAL SIGNIFICANCE**

With the increasing use of all-ceramic restorations, it is likely that the demand for aesthetic post and core systems will increase significantly.

**SUMMARY**

Relative to the metal posts, both the fibre-reinforced and ceramic posts are relative new additions for the treatment of the badly broken-down teeth. Considerably more knowledge and experience, both in vitro and in vivo, with the use of these materials is required before they can be accepted as readily as the metal post systems.
FURTHER READING