The Washington Study of endodontic success and failure suggests percolation of periradicular exudate into the incompletely filled canal as the greatest cause of endodontic failure. Nearly 60% of the failures in the study were apparently caused by incomplete obliteration of the radicular space (see chapter 13).

Dow and Ingle demonstrated *in vitro* the possibility of apical percolation using a radioactive isotope. After filling the root canals of extracted teeth, they placed the teeth in radioactive iodine ($^{131}$I). In teeth with a fluid-tight seal of the apical foramen and a well-obiterated canal space, there was no penetration of the radioactive iodine (Figure 11-1, A). In the poorly filled canals—filled so by design—a deep penetration into the canal by $^{131}$I was apparent in the radioautographs (Figure 11-1, B).

On the basis of this study, one might hypothesize that the penetration of radioactive iodine into a poorly filled root canal *in vitro* is analogous to fluid percolation into the canal of *in situ* pulpless teeth with incomplete canal obliteration (Figure 11-2). Apical percolation may be considered a logical hypothesis. However, the role of the end products of microleakage in the production of periradicular inflammation is open to speculation. It would seem safe to assume that the noxious products leaking from the apical foramen act as an inflammatory irritant. The unanswered question concerns the production of irritants in the canal. It is presently speculated that the transudate constantly leaking into the unfilled or partially filled canal arises indirectly from the blood serum and consists of a number of water-soluble proteins, enzymes, and salts. It is further speculated that the serum is trapped in the *cul-de-sac* of the poorly filled canal, away from the influences of the bloodstream, and undergoes degradation there. Later, when the degraded serum slowly diffuses out to the periradicular tissue, it acts as a physiochemical irritant to produce the periradicular inflammation of apical periodontitis.

Such a sequence of events might well explain the paradox of the periradicular lesion associated with a noninfected pulpless tooth. Periradicular inflamma-
tion is presumed to persist under the influence of any noxious substance. **Bacteria** certainly play a major role in the production of toxic products in the root canal. However, in the absence of bacteria, degraded serum *per se* may well assume the role of the primary tissue irritant. The persistence of periradicular inflammation, in the absence of bacterial infection, might thus be attributed to the continuing apical percolation of serum and its breakdown products.

Add a bacterial factor to this picture and the situation worsens. It is embarrassing to note that Prinz stated this thought nearly 90 years ago. Speaking before the St. Louis Dental Society on September 2, 1912, Dr. Prinz stated, “If the canal is not filled perfectly, serum will seep into it from the apical tissues. The serum furnishes nutrient material for the microorganisms present in the tubulii of a primarily infected root canal.”

As the Scandinavians have repeatedly pointed out, bacteria are the primary source of persistent periradicular inflammation and endodontic failure.

**OBJECTIVES**

From this discussion, it is apparent that the preliminary objectives of operative endodontics are total débridement of the pulpal space, development of a fluid-tight seal at the apical foramen, and total obliteration of the root canal. By the same token, one must not overlook the importance of a coronal seal. **Microleakage around coronal restorations**, down through the root canal filling, and out the apical foramen into the periradicular tissues is also a potential source of bacterial infestation.

Many studies on the preparation and obturation of root canals, however, indicate that most fillings do not completely fill the root canal system. The permeability of the dentin-filling interface has been demonstrated by

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*The commonly used term “hermetic seal” is not accurate. “Hermetic” is defined as “airtight by fusion or sealing.” Air is not the problem at the periapex—fluid is the problem. “Impermeable” is a more accurate term. Ramsey, WD. Hermetic sealing of root canals. JOE 1982;198:100.*
dye,\textsuperscript{7–14} radioisotope,\textsuperscript{1,15–19} electrochemical,\textsuperscript{20–22} fluorometric,\textsuperscript{23,24} and scanning electron microscopic examination.\textsuperscript{25,26} This is only a partial listing of the vast number of microleakage studies that have been done as endodontic research continues to seek improved sealing efficiency of new materials and techniques.

**EXTENSION OF THE ROOT CANAL FILLING**

The anatomic limits of the pulp space are the dentinocemental junction apically, and the pulp chamber coronally. Debate persists, however, as to the ideal apical limit of the root canal filling.

Canals filled to the apical dentinocemental junction are filled to the anatomic limit of the canal. Beyond this point, the periodontal structures begin (Figure 11-3). Under the rubric “Why Root Canals Should Be Filled to the Dentinocemental Junction,” three early endodontic advocates prescribed this limitation over 70 years ago.\textsuperscript{27–29} Two of them, Orban and Skillen, were world-renowned dental scientists.

The dentinocemental junction is an average of about 0.5 to 0.7 mm from the external surface of the apical foramen, as clearly demonstrated by Kuttler,\textsuperscript{30} and is the major factor in limiting filling material to the canal (Figure 11-4). A clarification in terminology is in order. Two terms, overfilling and overextension, are often used interchangeably. This is not correct. Overfilling denotes “total obturation of the root canal space with excess material extruding beyond the apical foramen.”\textsuperscript{31} Note the emphasis on “total obturation.” Overextension, on the other hand, may also denote extrusion of filling material beyond the apical foramen but with the caveat that the canal has not been adequately filled and the apex has not been sealed.\textsuperscript{31} It has been said facetiously that “overfilling happens to you, whereas overextension happens to the other guy.”

With these definitions in mind, let it be said that a number of dentists disagree with the contention that the terminus of the filling should be at the dentinocemental junction. They prefer instead to fill to the radiographic external surface of the root or just beyond. They seek to develop a small “puff” of overfilling (Figure 11-5).

Filling to the radiographic end of the root is actually overfilling, for as Figure 11-3 shows, the apical flare of the foramen is filled with periodontal tissue. Purposely overfilling to produce a periradicular “puff” is advocated primarily by the proponents of the diffusion technique or the softened gutta-percha technique. Ostensibly, the “puff” or “button” is designed to compensate for shrinkage of the filling by pulling down tightly against the apex. Although no proof exists that this is true, the advocates of softened gutta-percha fillings interpret the apical “puff” as an indicator that the gutta-percha has been densely packed into the apical

![Figure 11-4](image1.png) Instrumentation and root canal filling beyond apical limitation. Minor inflammatory and foreign body reaction has developed in response to irritant. (Courtesy of Dr. Seiichi Matsumiya.)

![Figure 11-5](image2.png) Periradicular “puff” (arrows) at four portals of exit, maxillary premolar, provides assurance that canals are filled.
preparation and that all of the aberrations, as well as the lateral and accessory canals of the root canal system, have been cleansed and filled. No accounting is given of postoperative discomfort. In any case, overfilled canals tend to cause more postoperative discomfort than do those filled to the dentinocemental junction.

Many authors believe that filling just short of the radiographic apex is greatly preferred to overfilling. Filling short of the apex following pulpectomy is especially recommended by Nygaard-Østby,32 Blayney,33 and most recently Strindberg.34 Horsted and Nygaard-Østby reported on pulpectomies of 20 vital human teeth, stating that the space between the gutta-percha-Kloropercha fillings and the tissue surface was filled by new connective tissue within a few months.35 They claimed the same results with clinically healthy and chronically inflamed pulps (Figure 11-6). The University of Washington study also found no failures among those well-obliterated cases in which the filling terminated slightly short of the apex, whereas 3.85% of the failures were caused by overfilling.

Despite all of this, a high degree of success is still achieved if overfilling occurs. Fortunately, most of the root canal sealers currently used, as well as the solid-core filling materials, are eventually tolerated by the periradicular tissues once the cements have set. The tissue reaction that does occur can be a fibrous walling off of the foreign body (Figure 11-7). On the other hand, fewer stormy postoperative reactions can be expected if canal instrumentation and filling are limited by the narrowest waist of the apical foramen.

WHEN TO OBTURATE THE CANAL

The root canal is ready to be filled when the canal is cleaned and shaped to an optimum size and dryness. Many feel that the smear layer lining the canal walls should also be removed. The tooth should be comfortable. Dry canals may be obtained with absorbent points except in cases of apical periodontitis or apical cyst, in which “weeping” into the canal persists.

The exception to the aforementioned criteria is the case in which mild discomfort persists. Experience has shown that filling the root canal in such cases usually alleviates the symptoms. However, filling a root canal known to be infected is risky. Ingle and Zeldow have described the increase in postoperative discomfort from filling infected root canals.36 They also have shown that the degree of success in a group of infected cases was 11.2% less than that in an a priori group of cases with negative bacteriologic cultures.37 More

Figure 11-6 Partial pulpectomy adequately obliterated to point of amputation. Even though root canal filling is short of apex, perfect healing has developed, as evidenced by normal pulp and periradicular tissue. (Courtesy of Dr. Seiichi Matsumiya.)

Figure 11-7 Tissue reaction to foreign body such as gutta-percha. (Courtesy of Dr. S.N. Bhaskar and US Army Institute of Pathology.)
recently, Sjögren and his associates in Sweden found that, after 5 years, 94% of those cases exhibiting negative cultures at the time they were filled were completely successful. In marked contrast, only 68% of the cases filled with positive cultures were successful after 5 years, a 26% difference in success rate.38

MATERIALS USED IN OBTURATION
The materials used to fill root canals have been legion, running the gamut from gold to feathers. Grossman grouped acceptable filling materials into plastics, solids, cements, and pastes.39 He also delineated 10 requirements for an ideal root canal filling material that apply equally to metals, plastics, and cements:

1. It should be easily introduced into a root canal.
2. It should seal the canal laterally as well as apically.
3. It should not shrink after being inserted.
4. It should be impervious to moisture.
5. It should be bacteriostatic or at least not encourage bacterial growth.
6. It should be radiopaque.
7. It should not stain tooth structure.
8. It should not irritate periradicular tissue.
9. It should be sterile or easily and quickly sterilized immediately before insertion.
10. It should be removed easily from the root canal if necessary.

Both gutta-percha and silver points meet these requirements. If the gutta-percha point has a fault, it lies in its inherent plasticity, for it requires special handling to position it. The major fault with the silver point is its lack of plasticity—it's inability to be compacted. Both must be cemented into place, however, to be effective.

Solid-Core Materials
Gutta-percha is by far the most universally used solid-core root canal filling material and may be classified as a plastic. To date, modern plastics have been disappointing as solid-core endodontic filling materials. However, new plastics are on the horizon. Silver amalgam, used in the retrosurgical technique wherein the canal is filled from the apex, must also be considered a “plastic” filling material.

Gutta-percha
Because modern petrochemical plastics have proved so disappointing for canal obturation, a new interest has developed in old-fashioned gutta-percha. First shown as a curiosity in the mid-seventeenth century, gutta-percha escaped notice as a practical product for nearly 200 years. The first successful use of the curious material seems to have been as insulation for underwater cables. This was in 1848, and patents followed for its use in the manufacture of corks, cement thread, surgical instruments, garments, pipes, and sheathing for ships. Some boats were made entirely of gutta-percha. Gutta-percha golf balls were introduced by the latter part of the nineteenth century; until 1920, golf balls were called “gutties.” Gutta-percha has been known to dentistry for over 100 years.40

Actually, true gutta-percha may not be the product presently supplied to the dental profession. Manufacturers privately admit they have long used balata, which is the dried juice of the Brazilian trees Manilkara bidentata, of the sapodilla family. Gutta-percha also comes from the sapodilla family, but from Malaysian trees, genera Payena or Palaquium. Chemically and physically, balata and gutta-percha appear to be essentially identical; investigators in this field may have been given balata to test and told it was gutta-percha. In any event, the point appears to be moot, and either product is here called “gutta-percha.”

Chemically pure gutta-percha (or balata) exists in two distinctly different crystalline forms (alpha and beta) that can be converted into each other. The alpha form comes directly from the tree. Most commercial gutta-percha, however, is the beta crystalline form.40 There are few differences in physical properties between the two forms, merely a difference in the crystalline lattice depending on the annealing and/or drawing process used when manufacturing the final product.41

Traditionally, the beta form of gutta-percha was used to manufacture endodontic gutta-percha points to achieve an improved stability and hardness and reduce stickiness. However, through special processing and/or modifications to the formulation of the gutta-percha compound, more alpha-like forms of gutta-percha have been introduced, resulting in changes in the melting point, viscosity, and tackiness of the gutta-percha point. Gutta-percha with low viscosity will flow with less pressure or stress,42 while an increase in tackiness will help create a more homogeneous filling. Various manufacturers have introduced products to take advantage of these properties (eg, Thermafil, Densfil, Microseal).

The effect of heating on the volumetric change of gutta-percha is most important to dentistry. Gutta-percha expands slightly on heating, a desirable trait for an endodontic filling material.43 This physical property manifests itself as an increased volume of material that may be compacted into a root canal cavity. Volumetric
studies show that it is possible to “overfill” a root canal preparation when heat and vertical condensation are applied because the volume of the gutta-percha filling is greater than the space it occupies.44

Although the material is thought to be compressed with force that would reduce its volume, studies have shown that it is actually compacted, not compressed,45 and increased volumetric changes are due to heating.

Unfortunately, warmed gutta-percha also shrinks as it returns to body temperature. Schilder et al. therefore recommend “that vertical pressure be applied in all warm gutta-percha techniques to compensate for volume changes that occur as cooling takes place.”46 Camps et al. found that, even though warm gutta-percha is easily compacted, the plugger must be introduced apically since permanent deformation is undergone only after a 50% reduction in volume.47 This contrasts with the use of cold gutta-percha in which an important pressure must be applied to obtain permanent deformation, but the spreaders do not have to be introduced apically since a 6% deformation is already permanent. Although techniques of gutta-percha placement involving heating in the root canal caused reversible physical changes, no apparent changes in chemical composition take place.48

Studies of pure gutta-percha are actually rather meaningless because endodontic gutta-percha contains only a fraction of gutta-percha per se. A study at Northwestern University49 of the chemistry of gutta-percha filling materials supplied by five manufacturers found only about 20% of the chemical composition to be gutta-percha, whereas the 60 to 75% of the composition is zinc oxide filler (Table 11-1). The remaining constituents are wax or resin to make the point more pliable and/or compactible and metal salts to lend radiopacity. On an organic versus inorganic basis, gutta-percha points are only 23.1% organic (gutta-percha and wax) and 76.4% inorganic fillers (zinc oxide and barium sulfate).49 High zinc oxide levels were found to increase brittleness in the points and decrease tensile strength. These percentages of composition essentially have been confirmed by a French group. However, they found that it is the high content of gutta-percha in the points that results in their brittleness.50

Gutta-percha points also become brittle as they age, probably through oxidation.51 Storage under artificial light also speeds their rate of deterioration.52 On the other hand, they can be rejuvenated somewhat by alternate heating and cooling.53

Evidence of slight antibacterial activity from gutta-percha points exists54; however, it is too weak to be an effective microbiocide. As the destruction of bacteria is key to endodontic success, a new formulation of gutta-percha that contains iodoform, Medicated Gutta-Percha (MGP) (Medidenta, Woodside, N.Y.), has been developed by Martin and Martin.55 Within the filled root canal, the iodine/iodoform depot in the MGP cone is a biologically active source for inhibiting microbial growth. The iodoform is centrally located within the gutta-percha and takes about 24 hours to leach to the surface. “The iodoform remains inert until it comes in contact with tissue fluids that activate the free iodine.”55 A canal filled with MGP gutta-percha could serve as a protection against bacterial contamination from coronal microleakage reaching the apical tissue. The use of heat during obturation does not affect either the release of the iodoform or its chemical composition.

Gutta-percha cones have also been introduced that contain a high percentage of calcium hydroxide (40–60%) (Roeko) to permit simple placement of the medicament within the canal space between appointments. Once the calcium hydroxide has leached out, the point is no longer useful as a filling material and must be removed. Holland et al. have reported on the use of

<table>
<thead>
<tr>
<th>Table 11-1</th>
<th>Mean (x) and Standard Deviation (SD) of Percentage Weights from Chemical Assay of the Gutta-percha Endodontic Filling Materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brand</td>
<td>Gutta-percha</td>
</tr>
<tr>
<td></td>
<td>x ± SD</td>
</tr>
<tr>
<td>Premier</td>
<td>18.9 ± 0.1</td>
</tr>
<tr>
<td>Mynol</td>
<td>19.9 ± 0.1</td>
</tr>
<tr>
<td>Indian Head</td>
<td>21.8 ± 0.2</td>
</tr>
<tr>
<td>Dent-O-Lux</td>
<td>19.9 ± 0.2</td>
</tr>
<tr>
<td>Tempryte</td>
<td>20.6 ± 1.4</td>
</tr>
</tbody>
</table>

*Colored residue found with metal sulfate.

Reproduced with permission from Friedman CE, Sandrik JL, Heuer MA, Rapp GW. JOE 1977;8:305.
an experimental calcium hydroxide containing gutta-percha cone that can be used for root canal filling. Their results indicated that these points produced an improvement in the apical sealing quality of the root canal filling.56

Beyond these biocide qualities, gutta-percha also exhibits a degree of tissue irritation, the latter probably related to the high content of zinc oxide, which is known to be an irritant.57 Wolfson and Seltzer found early on a severe tissue reaction to all eight brands of gutta-percha points injected into rat skin.58

Configuration

Gutta-percha points (or cones) are supplied in two shapes. The traditional form is cone shaped to conform to the perceived shape of the root canal. Today these cones are preferred by dentists who use the warm gutta-percha/vertical compaction technique of filling. Also, because the original spreaders used in the lateral compaction technique were shaped to match these cone shapes and sizes, traditional cones have long been used as the accessory cones in the lateral compaction technique.

The other shape of gutta-percha points is standardized to the same size and shape as the standardized (ISO) endodontic instruments. These points are available in the standardized .02 taper as well as in increased taper sizes (.04, .06, etc) to correspond to the newer tapered instrument sizes. Color coding the numbered points to match ISO instrument color has become routine and it is now rare to find the standardized points without these convenient markings (N. Lenz, personal communication). Although gutta-percha points are supposed to be standardized according to instrument size, a startling lack of uniformity has been found,59 as well as an alarming degree of deformation of the points in their apical third60 (Figure 11-8).

Before being used for root canal filling, gutta-percha points should be free of pathogenic microorganisms. Siqueira et al. studied four commonly used disinfectants and found that only 5.25% sodium hypochlorite was effective in eliminating Bacillus subtilis spores from gutta-percha cones after 1 minute of contact. Glutaraldehyde, chlorhexidine, and ethyl alcohol did not decontaminate the gutta-percha points even after 10 minutes of contact.61

Silver

Silver points are the most widely used solid-core metallic filling material, although points of gold, iridioplatinum, and tantalum are also available. Silver points may be indicated in mature teeth with small or well-calciﬁed round tapered canals: maxillary ﬁrst premolars with two or three canals, or the buccal roots of mature maxillary molars and mesial roots of mandibular molars if they are straight. In youngsters, even these canals are too large and too ovoid for single silver point use. Silver points are also not indicated for filling anterior teeth, single canal premolars, or large single canals in molars.

Silver points often fail when used outside these situations (Figure 11-9). These failures in judgment have given silver points a bad name. Seltzer and colleagues have dramatically shown that failed silver points are always black and corroded when removed from the canal.62 Goldberg has further noted that corrosion may be observed microscopically in cases previously judged to be successful by clinical and radiographic criteria.63 Kehoe reported a case of localized argyia of the buccal gingiva, a dark-blue pigmented “tattoo” surrounded by a gray halo (Figure 11-9, C), related to severe corrosion of a failing silver point64 (Figure 11-9, D).

Gutierrez and his associates in Chile found that canal irrigants corrode silver points.65 Brady and del Rio reported that sulfur and chlorides were detected by
Possibly the corrosion begins from within the canal, an aftermath of apical microleakage. From such studies and a good deal of clinical evidence, the assumption has developed that silver points always corrode. This need not be true if the round tapered point truly fits the round tapered cavity, sealing the foramen as a cork seals a bottle (Figure 11-10). The only cement depended on is a “flashing” between the silver and the dentin wall. Silver has more rigidity than gutta-percha and hence can be pushed into tightly fitting canals and around curves where it is difficult to force gutta-percha. In an effort to avoid the problems inherent in silver points, yet make use of their versatility, Messing suggested that points be made of titanium. After 3 years, Messing, using titanium, reported

Figure 11-9  Root canal filling failure after 20 years. A, Silver point incorrectly used in mandibular premolar. Pain and swelling were first indications of periradicular inflammation. B, Electron photomicrograph (×300 original magnification) of corroded silver point removed from canal seen in A. Moisture and decomposed cement were found in canal as well. C, Dark blue-pigmented lesion (argyria) surrounded by gray halo caused by leakage from silver point corrosion. D, Corroded silver point removed from lingual canal in C 10 years after insertion. (Electron photomicrograph, B, courtesy of Samuel Seltzer). C and D reproduced with permission from Kehoe JC.64
three failures caused by excessive canal curvature and “tear-drop” (“zip”) perforations with leakage, cases contraindicated for either titanium or silver.67

Sealers

In addition to the basic requirements for a solid filling material, Grossman listed 11 requirements and characteristics of a good root canal sealer68:

1. It should be tacky when mixed to provide good adhesion between it and the canal wall when set.
2. It should make a hermetic seal.
3. It should be radiopaque so that it can be visualized in the radiograph.
4. The particles of powder should be very fine so that they can mix easily with the liquid.
5. It should not shrink upon setting.
6. It should not stain tooth structure.
7. It should be bacteriostatic or at least not encourage bacterial growth.
8. It should set slowly.
9. It should be insoluble in tissue fluids.
10. It should be tissue tolerant, that is, nonirritating to periradicular tissue.
11. It should be soluble in a common solvent if it is necessary to remove the root canal filling.

One might add the following to Grossman’s 11 basic requirements:

12. It should not provoke an immune response in periradicular tissue.69–72
13. It should be neither mutagenic nor carcinogenic.73,74

Unfortunately, zinc oxide–eugenol (ZOE) paste and ZOE paste modified with paraformaldehyde have been found to alter dog pulp tissue, making it antigenetically active.75 Epoxy resin sealer (AH-26), on the other hand, “does not produce any systemic antibody formation or delayed hypersensitivity reaction.”72

As far as mutagenicity and carcinogenicity are concerned, Harnden73 reported that eugenol and its metabolites, although suspect, were uniformly negative in a bacterial mutagenicity test; hence the probability that eugenol is a carcinogen is relatively low.

Formaldehyde, formalin, and paraformaldehyde, on the other hand, are highly suspect. The US Consumer Product Safety Commission has issued warnings about the hazards of formaldehyde75 following a study on the subject by the National Academy of Sciences.76

In regard to some of the other 11 requirements originally elucidated by Grossman,68 it can be said that only polycarboxylates and glass ionomers satisfy requirement No. 1, good adhesion to dentin.77 Newer adhesives are being tested at this time, however, and some appear promising.
As far as requirement No. 2, the hermetic seal, is concerned, the literature is replete with evaluations of sealing effectiveness, many of them contradictory, and virtually all questionable as to their validity.\textsuperscript{78–80} This is discussed later in the chapter.

Radiopacity, requirement No. 3, is provided by salts of heavy metals and a halogen: lead, silver, barium, bismuth, or iodine. Beyer-Olsen and Orstavik measured the radiopacity of 409 root canal sealers and concluded that it would be difficult to compare radiographically the quality of root filling when such a variance exists in radiopacifiers.\textsuperscript{81}

Requirement No. 4, dealing with particle size, was also investigated by Orstavik, who found sealer film thicknesses, after mixing, ranging from 49 to 180 µm.\textsuperscript{82} There was no apparent correlation, however, between particle size and film thickness. He did point out the problems encountered with a thick film and proper sealing of the primary gutta-percha point. He found that some “sealers may prevent reinsertion of a gutta-percha point to its correct pre fitted position.”\textsuperscript{82}

Requirement No. 5, “It should not shrink upon setting,” is notoriously violated if a canal is filled with gutta-percha dissolved in chloroform. Whatever the volume of the chloroform in the mixture, that will be the percentage of shrinkage as the chloroform gradually evaporates.\textsuperscript{83} Moreover, all of the sealers shrink slightly on setting, and gutta-percha also shrinks when returning from a warmed or plasticized state. At the University of Connecticut Kazemi et al. found that ZOE sealers begin shrinking “within hours after mixing” but that AH-26...first expanded and showed no shrinkage for 30 days.” They concluded that “significant dimensional change and continued volume loss can occur in some endodontic sealers.”\textsuperscript{84}

The admonition that sealers and filling materials “should not stain tooth structure,” Grossman’s requirement No. 6, is evidently being violated by a number of sealers. Van der Burg from Holland and her associates reported that “Grossman’s cement, zinc oxide—eugenol, Endomethasone, and N2 induced a moderate orange-red stain” to the crowns of upper premolar teeth.\textsuperscript{85} She further found that “Diaket and Tubli-Seal caused a mild pink discoloration,” whereas “AH-26 gave a distinct color shift toward grey.” On the other hand, “Riebler’s paste caused a severe dark red stain.” Diaket caused the least discoloration.\textsuperscript{86} As far as the staining ability of other materials is concerned, Van der Burg found that Cavit produced “a light to moderate yellowish/green stain,” that “gutta-percha caused a mild pinkish tooth discoloration,” that “AH-26 Silver-Free and Duo Percha induced a distinct color shift towards grey” and that crowns filled with IRM and Dycal became somewhat darker. “No discolorations were recorded for teeth filled with Durelon, Fuji glass ionomer, Fletcher’s cement, or zinc phosphate cement.”\textsuperscript{87} Sealers that contain silver as a radiopacifier, such as Kerr’s Root Canal Sealer (Rickert’s Formula) or the original AH-26, are notorious as tooth stainers. All in all, it seems wise to avoid leaving any sealers or staining cements in the tooth crown.

Grossman himself investigated the significance of his requirement No. 7, bacteriostatic effect of sealers.\textsuperscript{88} After testing 11 root canal cements, he concluded that they all “exerted antimicrobial activity to a varying degree,” those containing paraformaldehyde to a greater degree initially. With time, however, this latter activity diminished, so that after 7 to 10 days the formaldehyde cements were no more bactericidal than the other cements.

A British group studying the antibacterial activity of four restorative materials reached much the same conclusion regarding ZOE and glass ionomer cements.\textsuperscript{89} Another study found that 10 sealers inhibited growth of Streptococcus sanguis and Streptococcus mutans.\textsuperscript{90} A Temple University study found that Grossman’s Sealer had the greatest overall antibacterial activity, but that AH-26 was the most active against Bacteroides endodontalis, an anaerobe.\textsuperscript{91} Heling and Chandler, at Hebrew University, also found AH26, within dentinal tubules, to have the strongest antimicrobial effect over three other well-known sealers.\textsuperscript{92} The Dundee University group, working with anaerobes, found, in descending order of antimicrobial activity, Roth Sealer (Grossman’s) to be the best, followed by Ketac-Endo, Tubliseal, Apexit, and Sealapex.\textsuperscript{93} Mickel and Wright also found Roth Sealer to be more bactericidal than the calcium hydroxide sealers and attributed the effect to the concentration of eugenol.\textsuperscript{94} From Germany, Schafer and Bossman reported on the efficacy of a new liquid antimicrobial, camphorated chloroxylenol (ED 84), as a good “temporary root canal dressing for a duration of 2 days.” For a longer term dressing, they recommended calcium hydroxide.\textsuperscript{95}

Grossman stated in requirement No. 9 that sealers should not be soluble in tissue fluids. Smith\textsuperscript{96} and McComb and Smith\textsuperscript{97} found a wide variance in sealer solubility after 7 days in distilled water, ranging from 4% for Kerr’s Pulp Canal Sealer to much less than 1% for Diaket (Figure 11-11). Peters found after 2 years that virtually all of the sealer was dissolved out of test teeth filled by lateral or vertical compaction.\textsuperscript{98} Therefore most sealers are soluble to some extent.
The very important requirement No. 10, tissue tolerance, will be dealt with at length later in the chapter. Suffice it to say at this time that the paraformaldehyde-containing sealers appear to be the most toxic and irritating to tissue. A case in point is reported from Israel: necrosis of the soft tissue and sequestration of crestal alveolar bone from the leakage of paraformaldehyde paste from a gingival-level perforation.99

Cements, Plastics, and Pastes

The cements, which have wide American acceptance, are primarily ZOE cements, the polyketones, and epoxy. The pastes currently in worldwide vogue are chlorapercha and eucapercha, as well as the iodoform pastes, which include both the rapidly absorbable and the slowly absorbable types. Despite their disadvantages, pastes are applicable in certain cases. The plastics show promise, as do the calcium phosphate products. At present the methods most frequently used in filling root canals involve the use of solid-core points, that are inserted in conjunction with cementing materials. Gutta-percha and silver per se are not considered adequate filling material unless they are cemented in place in the canal. The sealers are to form a fluid-tight seal at the apex by filling the minor interstices between the solid material and the wall of the canal, and also by filling patent accessory canals and multiple foramina. Dye-immersion studies have shown the necessity of cementation, without which dye penetrates back into the canal after compaction; this occurs with all known solid-core root canal-filling techniques.

Cements

Zinc Oxide–Eugenol. An early ZOE cement, developed by Rickert (Kerr Pulp Canal Sealer; Kerr Dental; Orange, Calif.), has been the standard of the profession for years. It admirably met the requirements set down by Grossman except for severe staining. The silver, added for radiopacity, causes discoloration of the teeth, thus creating an undesirable public image for endodontics. Removing all cement from the crowns of teeth would prevent these unfortunate incidents.100

Pulp Canal Sealer (PCS) has more recently emerged as the favorite sealer of the warm gutta-percha, vertical condensation adherents. However, one of its disadvantages was the rapid setting time in high heat/humidity regions of the world. To solve this problem, Kerr reconfigured the formula into Pulp Canal Sealer EWT (Extended Working Time) (Sybron Endo/Kerr; Orange, Calif.) that now has a “6 hour working time.” The regular-set cement is also still available. Recent apical microleakage studies have shown the regular Pulp Canal Sealer (PCS) to be “significantly better than Roth 801 and AH26 at 24 weeks.”101 Additional research, comparing sealing ability between regular Pulp Canal Sealer and the new EWT sealer, found no significant difference between the two.102

In 1958 Grossman recommended a nonstaining ZOE cement as a substitute for Rickert’s formula.103 Now available as Roth’s Sealer, it has become the standard by which other cements are measured because it reasonably meets most of Grossman’s requirements for cement. The formula is as follows68:

<table>
<thead>
<tr>
<th>Powder</th>
<th>Liquid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zinc oxide, reagent</td>
<td>Eugenol</td>
</tr>
<tr>
<td>Staybelite resin</td>
<td></td>
</tr>
<tr>
<td>Bismuth subcarbonate</td>
<td></td>
</tr>
<tr>
<td>Barium sulfate</td>
<td></td>
</tr>
<tr>
<td>Sodium borate, anhydrous</td>
<td></td>
</tr>
</tbody>
</table>

42 parts
27 parts
15 parts
15 parts
1 part

This cement is available commercially as Roth’s 801 (Roth’s Pharmacy, USA) or U/P Root Canal Sealer (Sultan, USA).
All ZOE cements have an extended working time but set faster in the tooth than on the slab because of increased body temperature and humidity. If the eugenol used in the preceding nonstaining cement becomes oxidized and brown, the cement sets too rapidly for ease of handling. If too much sodium borate has been added, the setting time is overextended.

The main virtues of such a cement are its plasticity and slow setting time in the absence of moisture, together with good sealing potential because of the small volumetric change on setting. Zinc eugenate has the disadvantage, however, of being decomposed by water through a continuous loss of the eugenol. This makes ZOE a weak, unstable material and precludes its use in bulk, such as for retrofillings placed apically through a surgical approach. Other zinc oxide–type cements in use are TubliSeal (Sybron Endo/Kerr; Orange, Calif.), Wach’s Cement (Roth’s Pharmacy, Chicago III.), and Nogenol (G-C America; Alsip, Ill. and Japan).

As Kerr’s PCS fell into some disfavor because of staining, the company developed a nonstaining sealer, TubliSeal. Marketed as a two-paste system, it is quick and easy to mix. It differs from Richert’s cement in that its zinc oxide–base paste also contains barium sulfate as a radiopacifier as well as mineral oil, cornstarch, and lecithin. The catalyst is made up of a polypalate resin, eugenol, and thymol iodide. If the advantage of TubliSeal is its ease of preparation, its disadvantage has been its rapid set, especially in the presence of moisture. The company has reformulated the sealer to extend working time, and it is now available as Sealapex Regular or Sealapex EWT (Extended Working Time).

Wach’s Cement. Meanwhile, in the Chicago area, Wach’s cement became popular. A much more complicated formula, its powder base consists of zinc oxide, with bismuth subnitrate and bismuth subiodide as radiopacifiers, as well as magnesium oxide and calcium phosphate. The liquid consists of oil of clove along with eucalyptol, Canada balsam, and beechwood creosote.

The advantage of Wach’s is a smooth consistency without a heavy body. The Canada balsam makes the sealer tacky. A disadvantage is the odor of the liquid—like that of an old-time dental office.

At one time, medicated variations of ZOE cements were very popular and, to some extent, remain so today. N2 and its American counterpart, RC2B, are the best examples, along with Spad and Endomethasone in Europe. There is no evidence that these products seal canals better than or as well as other sealers. However, there is evidence that they dissolve in fluid and thus break the seal.

The one common denominator of these medicated sealers is formaldehyde in one form or another. Since formalin is such a tissue-destructive chemical, it is no wonder that every cytotoxic test lists these sealers as the number one irritant.

It is the claim of their advocates that these sealers constantly release antimicrobial formalin. This appears to be true, but it is this dissolution that breaks the seal and leads to their destructive behavior (see “Tissue Tolerance of Root Canal Sealers, Cements, and Pastes”).

Nogenol was developed to overcome the irritating quality of eugenol. The product is an outgrowth of a noneugenol periodontal pack. The base is zinc oxide, with barium sulfate as the radiopacifier along with a vegetable oil. Set is accelerated by hydrogenated rosin, methyl abietate, lauric acid, chlorothymol, and salicylic acid. Removing eugenol from Nogenol evidently does exert the sought-after effect of reducing toxicity.

It seems quite obvious that “...all these root canal cements differ widely in setting times, plasticity and physical properties. None of the materials show hermetic [sic] sealing in the literal sense.”

Calcium Hydroxide Sealers. In the second edition of Endodontics (1976), Luebke and Ingle first forecast a new paradigm for endodontics: a broader use of calcium hydroxide in medicating and sealing the root canal. This is coming to pass, particularly with the introduction of the calcium hydroxide sealers.

CRCS (Calciobiotic Root Canal Sealer, Coltene/Whaledent/Hygenic; Mahwah, N.J.) is essentially a ZOE/eucalyptol sealer to which calcium hydroxide has been added for its so-called osteogenic effect. CRCS takes 3 days to set fully in either dry or humid environments. It also shows very little water sorption. This means it is quite stable, which improves its sealant qualities, but brings into question its ability to actually stimulate cementum and/or bone formation. If the calcium hydroxide is not released from the cement, it cannot exert an osteogenic effect, and thus its intended role is negated.

SealApex (Sybron Endo/Kerr; Orange, Calif.) is also a calcium hydroxide–containing sealer delivered as paste to paste in collapsible tubes. Its base is again zinc oxide, with calcium hydroxide as well as butyl benzene, sulfonamide, and zinc stearate. The catalyst tube contains barium sulfate and titanium dioxide as radiopacifiers as well as a proprietary resin, isobutyl salicylate, and aerocil R972. In 100% humidity, it takes up to 3 weeks to reach a final set. In a dry atmosphere, it never sets. It is also the only sealer that expands while setting. As with CRCS, the question remains: Is SealApex soluble in tissue fluids to release the calcium hydroxide for its osteogenic effect? And if so, does this dissolution lead to an inadequate seal?
At Creighton University it was established that, in a limited surface area, such as in a minimal apical opening, “a negligible amount of dissolution occurred.” At Baylor University, however, Gutmann and Fava found in vivo that extruded SealApex disappeared from the periapex in 4 months. This dissolution did not appear to delay healing. However, the authors suspected sealer dissolution may continue within the canal system as well, thus eventually breaking the apical seal. If water sorption is an indicator of possible dissolution, SealApex showed a weight gain of 1.6% over 21 days in water. In contrast, CRCS gained less than 0.4%. The fluid sorption characteristics of SealApex may be due to its porosity, which allows marked ingress of water.

LIFE (Sybron Endo/Kerr; Orange, Calif.), a calcium hydroxide liner and pulp-capping material similar in formulation to SealApex, has also been suggested as a sealer.

From Liechtenstein comes an experimental calcium hydroxide sealer called Apexit (Vivadent; Schaan, Liechtenstein). Australians found that it sealed better than SealApex and ImbiSeal.

Japanese researchers have introduced a calcium hydroxide sealer that also contains 40% iodoform. It is named Vitapex (NEO Dental, Japan), and its other component appears to be silicone oil. Iodoform, a known bactericide, is released from the sealer to suppress any lingering bacteria in the canal or periapex. One week following deposits in rats, Vitapex, containing 45Ca-labeled calcium hydroxide, was found throughout the skeletal system. This attests to the dissolution and uptake of the iodoform material. No evidence is given about the sealing or osteogenic capabilities of Vitapex.

NEO Dental has also produced another ZOE-type sealer that contains not only iodoform but calcium hydroxide as well. It is called Dentalis and is distributed in North America by DiaDent, Canada. It sets rapidly (5 to 7 minutes) and is very tacky.

Martin has also introduced a US Food and Drug Administration (FDA)-approved ZOE sealer, MCS, Medicated Canal Sealer (Medidenta, Woodside, N.Y.), that contains iodoform, to go along with MGP gutta-percha points that also contain 10% iodoform. Testing of MCS in vitro showed that it developed a bacterial zone of inhibition twice the size of regular ZOE sealer.

Researchers in Germany have also developed an experimental calcium hydroxide sealer that was reported on favorably by Pitt-Ford and Rowe.

**Plastics and Resins**

Other sealers that enjoy favor worldwide are based more on resin chemistry than on essential oil catalysts.

Diaket (3M/Espe; Minneapolis, Minn.), an early one first reported in 1951, is a resin-reinforced chelate formed between zinc oxide and a small amount of plastic dissolved in the liquid B-diketone. A very tacky material, it contracts slightly while setting, which is subsequently negated by uptake of water. In a recent dye-penetration study, the sealing ability of Diaket was similar to Apexit but significantly better than Ketac-Endo (3M/Espe; Minneapolis, Minn.).

AH-26 (Dentsply/Maillefer, Tulsa, Okla.), an epoxy resin, on the other hand, is very different. It is a glue, and its base is biphenol A-epoxy. The catalyst is hexamethylene-tetramine. It also contains 60% bismuth oxide for radiographic contrast. As AH-26 sets, traces of formaldehyde are temporarily released, which initially makes it antibacterial. AH-26 is not sensitive to moisture and will even set under water. It will not set, however, if hydrogen peroxide is present. It sets slowly, in 24 to 36 hours. The Swiss manufacturers of AH-26 recommend that mixed AH-26 be warmed on a glass slab over an alcohol flame, which renders it less viscous. AH-26 is also sold worldwide as ThermaSeal (Dentsply/Tulsa; Tulsa, Okla.).

Recognizing the advantages of AH-26 (high radiopacity, low solubility, slight shrinkage, and tissue compatibility), as well as some of its disadvantages (formaldehyde release, extended setting time [24 hours], and staining), the producers of AH26 set out to develop an improved product they renamed AH PLUS (Dentsply International). They retained the epoxy resin “glue” of AH26 but added new amines to maintain the natural color of the tooth. AH Plus comes in a paste–paste system, has a working time of 4 hours and a setting time of 8 hours, half the film thickness and half the solubility of regular AH26, and may be removed from the canal if necessary. In a comparative toxicity study, AH Plus was found to be less toxic than regular AH-26. AH Plus is also sold worldwide as ThermaSeal Plus (Dentsply/Tulsa; Tulsa, Okla.).

**Glass ionomer cements** have also been developed for endodontics. One of these is presently marketed as Ketac-Endo (3M/Espe; Minneapolis, Minn.). Saito appears to have been an early proponent of endodontic glass ionomers. He suggested using Fuji Type I luting cement to fill the entire canal. Pitt-Ford in England recommended endodontic glass ionomers as early as 1976.

However, he found the setting time too rapid. Stewart was combining Ketac-Bond and Ketac-Fil before these glass ionomers were specifically formulated for endodontics. He was pleased with the result in six cases.

At Temple University, eight different formulations of Ketac cement were researched for ease of manipulation,
radiopacity, adaptation of the dentin–sealer interface, and flow. Ray and Seltzer chose the sealer with the best physical qualities: the best bond to dentin, the fewest voids, the lowest surface tension, and the best flow. A method of triturating and injecting the cement into the canal was also developed. Ketac-Endo was the outcome.

In a follow-up study, the Temple group evaluated the efficacy of Ketac-Endo as a sealer in obturating 254 teeth in vivo. At the end of 6 months, they reported a success and failure rate comparable to that of other studies using other sealers.118

Their greatest concern was the problem of removal in the event of re-treatment since there is no known solvent for glass ionomers. A Toronto/Israel group reported, however, that Ketac-Endo sealer “can be effectively removed by hand instruments and chloroform solvent followed by one minute with an ultrasonic No. 25 file.”119

More recently, leakage studies compared Ketac-Endo with AH26120,121 and Roth’s 801E and AH26.122 US Navy researchers found “Ketac-Endo allowed greater dye penetration than Roth’s 801E and AH26.”122 On the other hand, the Amsterdam group found AH26 “leaked more than Ketac-Endo.” They related the difference to film thickness: 39 microns for AH26 and 22 microns for Ketac-Endo.120 In addition, the new AH product, AH Plus, has half the film thickness of regular AH26. Conversely, a Turkish group found “no statistical differences” in leakage between Ketac-Endo and AH26.121

As far as toxicity is concerned, two Greek studies found “Ketac-Endo to be a very biocompatible material.” The first study compared Ketac-Endo to Endion, which they found to be “highly toxic,”123 and the second study found only mild inflammation with Ketac-Endo, whereas TubliSeal (Sybron Endo/Kerr; Orange, Calif.) caused necrosis and inflammation as long as 4 months later.124 A study from Mexico, however, found that Ketac Silver, the precursor to Ketac-Endo, “induces irreversible pulpal damage.”125

Experimental Sealers
In the never-ending search for the perfect root canal sealers, new fields have been invaded, including resin chemistry, which is proving so successful in restorative dentistry, and calcium phosphate cements, which are a return to nature.

Early on, at Tufts University, a group experimented with a Bis GMA unfilled resin as a sealer.126 The new material was found to be biocompatible but impossible to remove.

Low-viscosity resins such as pit and fissure sealants have also been tried as sealers but “would not seem suitable as root canal filling materials.”127 Close adaptation depends on smear-layer removal, which is difficult to achieve in the apical third of the canal.

At Loma Linda University, isopropyl cyanoacrylate was found to be more adequate in sealing canals than were three other commercial sealers.128 However, further research was discontinued because of a lack of acceptance by the FDA (M. Torabinejad, personal communication, August 1997).

A polyamide varnish, Barrier (Interdent, Inc; Culver City, Calif.), has also been tried as a sealer but was found to be not as effective as ZOE.129

At the University of Minnesota, the efficacy of four different dentin bonding agents used as root canal sealers was tested. “No leakage was measurable in 75% of the canals sealed with Scotchbond (3-M Corporation; South El Monte, Calif.), in 70% of canals sealed with Restodent (Lee Pharmaceuticals; St. Paul, Minn.), in 60% of canals sealed with DentinAdhesit (Ivoclar; Schaan, Liechtenstein), and in only 30% of canals sealed with GLUMA130 (Bayer Dental; Laver Kusan, Germany). The same researchers reported the “dramatic improvement in the quality of sealing root canals using dentin bonding agents.”131

It seems quite probable that dentin bonding agents will play a major role in sealant endodontics. Their ability to halt microleakage is a superb requisite for future investigation. The Minnesota study130 returned to single-cone gutta-percha filling with the adhesives, the cone inserted undoubtedly to spread the adhesive laterally and to occupy space to reduce shrinkage. One might even visualize a rebirth of the silver point combined with one of the adhesives such as Amalgambond (Parkell Co., Farmingdale, N.Y.), which adheres to dentin as well as to metals.

From Zagreb, Croatia, a group used two different compaction methods, vertical and lateral, to condense composite resin with a bonding agent as a total filling material. They first developed an apical plug with bonding agent Clearfil (Morita Co.; Irvine, Calif. and Japan) and then photopolymerized layer by layer of composite resin with an argon laser as they compacted the composite with pluggers. They found fewer voids in their final filling than with lateral condensation132 (Figure 11-12).

From Siena, Italy, another group used dentin bonding agents, along with AH26 sealer and gutta-percha laterally condensed, to obturate canals for leakage tests. They found less leakage in those cases in which the bonding agents were used along with AH26 versus AH26 alone.133

Problems
Some obvious obstacles must be overcome, however, before these bonding agents become commercial
endodontic sealants. First is preparation of the dentin to remove all of the smear layer. As Rawlinson pointed out, it is very difficult to remove all of the smear from the apical third canal, even if sodium hypochlorite and citric acid are used with ultrasonic debridement.127

A second obstacle is radiopacity. Radiopaquing metal salts must be added to the adhesive, and this is sure to upset the delicate chemical balance that leads to polymerization.134 All of the bonding agents are very technique sensitive, and many do not polymerize in the presence of moisture or hydrogen peroxide.135 The third problem is placement: Which delivery system will best ensure a total, porosity-free placement?136 A final obstacle is removal in the event of failure. These resins polymerize very hard, all the more reason to place a gutta-percha core allowing future entry down the canal.

Calcium Phosphate Obturation
The possibility that one could mix two dry powders with water, inject the mixture into a root canal, and have it set up as hard as enamel within 5 minutes is exciting, to say the least. And yet just such a possibility may be emerging.

Developed and patented at the American Dental Association (ADA) Paffenbarger Research Center at the National Institute of Standards and Technology by Drs. W. E. Brown and L. C. Chow and their associates, calcium phosphate cements might well be the future ideal root canal sealer, long sought but never achieved.137,138 In mixing two variations of calcium phosphate with water, Brown and Chow demonstrated that hydroxyapatite would form. The pros and cons of calcium phosphate (hydroxyapatite) obturation is discussed in greater detail at the end of this chapter (see “A New Endodontic Paradigm”).

Sealer Efficacy
Hovland and Dumsha probably summarized it best: “Although all root canal sealers leak to some extent—there is probably a critical level of leakage that is unacceptable for healing, and therefore results in endodontic failure. This leakage may occur at the interface of the dentine and sealer, at the interface of the solid core and sealer, through the sealer itself, or by dissolution of the sealer.”139 And one might add, “microleakage from the crown down alongside even a well-compacted root filling.” The authors went on to find that Sealapex was no different after 30 days than TubliSeal or Grossman’s Sealer when it comes to leakage.139

No question, there is a variance in the impermeability of the many sealers on the market. The literature is replete with test after test, most done without prejudice but some done to promote a product. Microleakage research can be “rigged” to prove a point. “Should I use radioisotopes, or should I use India ink with its large particle size? Should I use methylene blue or should I use bacteria larger than the tubuli? Should I allow the sealer to set on the bench top or in 100% humidity? Should I test immediately, at 24 hours, 1 week, 1 month? Should the tests be done under normal atmospheric pressure or under vacuum? Should I centrifuge the test pieces? Should I remove the smear layer?” All of these factors have been shown to affect sealability results materially, to favor one product over another.

In choosing a sealer, factors other than adhesion must be considered: setting time, ease of manipulation,
antimicrobial effect, particle size, radiopacity, proclivity to staining, dissolvability, chemical contaminants (hydrogen peroxide, sodium hypochlorite), cytotoxicity, cementogenesis, and osteogenesis.

Therefore, rather than quoting from the endless list of reports, each one suppressing or refuting another, a résumé will be presented and a long list of references provided for perusal by the interested student.

**Résumé of Adhesion.** All presently available sealers leak; they are not impermeable. That is the first caveat. The second is that some leak more than others, mostly through dissolution. The greater the sealer/peri-radicular tissue interface, that is, apical perforations or blunderbuss open apices, the faster dissolution takes place. It goes without saying that readily dissolving sealers are not indicated in these cases.

**Zinc Oxide, Calcium Hydroxide-Type Sealers.** In a 2-year solubility study, Peters found that ZOE sealer was completely dissolved away. This fact alone should cause one to question the advisability of totally filling the canal with ZOE cement.

One might think that first lining the canal with varnishes such as Barrier or Copalite might improve the seal, but neither does.

On the basis of leakage studies alone one would be hard pressed to favor one of the ZOE or zinc oxide-calcium hydroxide sealers over the others. Kerr’s Pulp Canal Sealer (Rickert’s), Nonstaining Root Canal Sealer (Grossman’s), Wach’s Sealer, TubliSeal, Nogenol, CRCS, SealApex, Vitapex, Apexit, or even Dycal or Life, all appear to “be a wash” when numerous studies are examined. A study comparing the newer Kerr Pulp Canal Sealer EWT (Extended Working Time) versus the original Pulp Canal Sealer found no significant difference in microleakage. Moreover, recent studies comparing Pulp Canal Sealer (PCS) with Roth 801 and AH26 found PCS a “significantly better” sealer.

The reports are not as favorable, however, for the paraformaldehyde-containing sealers N2, RC2B, Spad, and Endomethasone. Sargenti has asserted that obliteration, along with disinfection, is important for success. On the other hand, he has stated that it is “not mandatory to have a compact root canal filling.” He also claims that N2 is not resorbed from the canal but is slowly absorbed from the periradicular tissues, an action he calls “semi-resorbable.” At another time and place, he modifies the statement by saying that N2 is “practically non-resorbable from the canal.” Yates and Hembree found N2 to be the least effective sealer when compared with TubliSeal or Diaket after 1 year. Block and Langeland reported 50 failed cases treated with N2 or RC2B.

More recent studies relating to zinc oxide-base sealers (and those previously referenced) have found essentially the same results for ZOE and calcium hydroxide sealer solubility, leakage, and bacterial inhibition. Despite their deficiencies, ZOE cements and their variations continue to be the most popular root canal sealers worldwide. But they are just that, sealers, and any attempt to depend on them wholly or in great part materially reduces long-term success. That is the principal reason why silver points failed—to little solid core and too much cement in an ovoid canal (see Figure 11-9, A).

If the apical orifice can be blocked principally by solid-core material, success is immeasurably improved over the long term, if not for a lifetime. On the other hand, in every study in which obturation without sealers is attempted, the leakage results are enormously greater. Sealers are necessary! Researchers agree, however, that thorough cleaning and shaping of the canal space are the key to perfect obturation.

**Plastic and Resin-Type Sealers.** It seems reasonable to assume that plastics, resins, and glues should be more adhesive to dentin and less resorbable than the mineral oxide cements. But they have not proved to be dramatically so. In one study, AH-26 was found comparable to ZOE sealer but better than six others. In another study, AH-26 and Diaket were “found satisfactory as sealers” along with all the ZOE products. Another study found Diaket less effective than TubliSeal but better than N2. In a recent Australian study, however, AH-26 was found to have better sealing capabilities than were three other cements: Apexit, Sealapex, and TubliSeal. In New Zealand, however, Sealapex outperformed AH-26 up to the twelfth week, but there was no significant difference after that time.

As far as the new glass ionomer cement, Ketac-Endo, is concerned, Ray and Seltzer found it superior to Grossman’s Sealer, but others found it difficult to remove in re-treatment. More recently, Dutch researchers found Ketac superior in sealing to AH26. On the other hand, US Navy researchers found Roth’s 801E and AH26 superior to Ketac Endo. Moreover, one Turkish group found Apexit and Diaket superior to Ketac, but a second Turkish group found no difference. It would appear the “jury is still out” on the sealing ability of Ketac Endo.

The early leakage reports on the adhesives used experimentally as root canal sealers are most encouraging. A 1987 report, when adhesives were in their infancy, placed Scotchbond first, with “no leakage measura-
ble in 75% of the canals” and GLUMA last, with 30% showing no leakage.\textsuperscript{130,131} Adhesives today are in their third and fourth generations, far superior to the initial resins. Also, there are adhesives such as C \& B Metabond (Parkell Co., USA) or All Bond (Bisco Products, USA) that actually polymerize best in a moist environment. Canals obturated for leakage studies with laterally condensed gutta-percha sealed with a combination of dentin bonding agents plus AH26 versus AH26 alone were found to be superior.\textsuperscript{133}

A thoroughly modern approach of sealing the apical foramen with a resin bond called Clearfil (Morita Co., Irvine, Calif.), followed by obturation with a composite resin condensed laterally as it was being photopolymerized in the canal with an argon laser, layer by layer, shows promise for the future (see Figure 11-12).\textsuperscript{132}

With any use of dentin adhesives and/or composite resin, it is imperative that the smear layer be removed so that the hybrid layer may form against the dentin and the adhesive is able to flow into the dentinal tubuli (see Figure 11-12, B). Once again, the difficulty of removing the smear layer in the apical region must be emphasized.\textsuperscript{127}

**Experimental Calcium Phosphate Sealers (CPC).** Already, the early reports on Japanese apatite sealers find them comparable to Sealapex but better sealants than two other ZOE cements.\textsuperscript{163}

Studies emanating from the A.D.A. Paffenbarger Center find calcium phosphate cements very preferable for their sealing properties as well as for tissue compatibility. In one study, they proved better sealants than a ZOE/gutta-percha filling.\textsuperscript{164} In another study, researchers found that the apatite injectable material “demonstrated a uniform and tight adaptation to the dentinal surfaces of the chambers and root canal walls.” CPC also infiltrated the dentinal tubules.\textsuperscript{165} Since these sealers set as hydroxyapatite, one must be aware that they are very difficult, but not impossible, to remove from the canal.

**Tissue Tolerance of Root Canal Sealers, Cements, and Pastes**

Without question, all of the materials used at this juncture to seal root canals—gutta-percha, silver, the sealers, cements, pastes, and plastics—irritate periapical tissue if allowed to escape from the canal. And, if placed against a pulp stump, as in partial pulpectomy, they irritate the pulp tissue as well. The argument seems to be not whether the tissue is irritated when this happens but rather to what degree and for how long it is irritated, as well as which materials are tolerable or which are intolerable irritants.

At present, four approaches are being used to evaluate scientifically (as opposed to empirically) the toxic effects of endodontic materials: (1) cytotoxic evaluation, (2) subcutaneous implants, (3) intraosseous implants, and (4) in vivo periradicular reactions. The studies done on the toxicity of the materials in question are categorized into these four evaluative methods.

**Cytotoxic Evaluation.** Cytotoxic studies are done by measuring leukocyte migration in a Boyden chamber; by measuring the effect that suspect materials or their extracts have on fibroblasts or HeLa cells in culture; or by using radioactively labeled tissue culture cells, or tissue culture—agar overlay, or a fibroblast monolayer on a millipore filter disk. The results are quite similar.

The numerous cytotoxic evaluations may be summarized by stating that a disappointing number of today’s sealers are toxic to the very cells they have been compounded to protect. Some of them are toxic when first mixed, while they are setting over hours, days, or weeks, and some continue to ooze noxious elements for years. This is, of course, caused by dissolution of the cement, thus releasing the irritants. All of the zinc oxide-type sealers, for example, gradually dissolve in fluid, releasing eugenol, which Grossman, in 1981, pointed out “is a phenolic compound and is irritating” (L.I. Grossman, personal communication, August 1981). More recently, this has been confirmed by the group in Verona, Italy.\textsuperscript{166}

Chisolm introduced zinc oxide and oil of clove (unrefined eugenol) cement to dentistry in 1873.\textsuperscript{167} One would think that after 125 years something less toxic would be the favorite root canal sealer.\textsuperscript{167} Eugenol is not only cytotoxic but neurotoxic as well.\textsuperscript{168}

**Zinc oxide and eugenol,** even when calcium hydroxide is added to the mixture, has been found universally to be a leading cytotoxic agent.\textsuperscript{168-181} Removing eugenol (or any of the essential oils) from the mixture greatly reduces the toxicity. Witness the spectacular differences in cytotoxicity when unsaturated fatty acids are substituted for eugenol and/or eucalyptol in sealers such as Nogenol or experimental Japanese sealers.\textsuperscript{105,182,183}

Eugenol alone is not the only culprit in ZOE irritation. **Zinc oxide itself must also be indicted.** Early on, Das found zinc oxide to be quite toxic.\textsuperscript{57} More recently, Meryon reported that the cytotoxicity of ZOE cement may be based more on the possible toxic effect of zinc ions.\textsuperscript{184} Maseki et al. also indicated that zinc might be a major offender when they found that dilutions of eugenol released from set cement allowed viability of 75% of their test cells.\textsuperscript{185}

Toxicity from zinc ions may well extend beyond that found in sealers. In testing the toxicity of gutta-percha
points, Pascon and Spångberg concluded that all brands of points were “highly cytotoxic” and further that although “…pure raw gutta-percha was nontoxic, zinc oxide…showed high toxicity.” The toxicity of gutta-percha points was attributed to leakage of zinc ions into the fluids.\textsuperscript{186} Adding calcium hydroxide to ZOE-type cements mollifies their toxicity somewhat.\textsuperscript{178,179}

If one were forced to classify popular ZOE-type sealers from worst to best as far as cytotoxicity studies are concerned, one would have to rank the pure ZOE sealers as worst: Grossman’s and Rickert’s, followed by Wach’s and TubliSeal, Sealapex, CRCS, and finally Nogenol.\textsuperscript{183} although there is not universal agreement on this total ranking. At Loma Linda University, for example, TubliSeal was found the least toxic followed by Wach’s and Grossman’s,\textsuperscript{175} whereas at Connecticut, Wach’s ranked ahead of TubliSeal.\textsuperscript{174} Later at the University of Connecticut, however, researchers reporting in vitro studies found TubliSeal to be “virtually non-toxic at all experimental levels.”\textsuperscript{177} In marked contrast, a Greek group reported in vivo studies showing TubliSeal exhibited “severe inflammation and necrosis as long as 4 months later.”\textsuperscript{124} The same group also found Apexit (a calcium hydroxide additive sealer) and Kerr’s classic Pulp Canal Sealer (ZOE) remained as irritants over a 4-month period.\textsuperscript{187} Researchers in India also found TubliSeal severely toxic at 48 hours and 7 days but not so at 3 months.\textsuperscript{188}

An extensive study in Venezuela found that CRCS (ZOE-calcium hydroxide additive) was the least cytotoxic against human gingival fibroblasts, followed by Endomet and AH26. They also reported that MTA (Dentsply/Tulsa; Tulsa, Okla.) root-end filling material was not cytotoxic.\textsuperscript{189} Another study of calcium hydroxide-containing sealers found that, with Sealapex, “no inflammatory infiltrate occurred,” whereas with CRCS, a “moderate inflammatory infiltrate occurred.” Inflammation “of the severe type” accompanied Apexit.\textsuperscript{190}

Paraformaldehyde-containing sealers “are something else.” Not only do they generally contain zinc oxide and eugenol, but they also boast 4.78 to 6.5% highly toxic paraformaldehyde. Virtually every cytotoxic study on N2, RC2B, Treatment SPAD, Endomethasone, Triolon, Opara, Riebler’s paste, and so forth finds these materials to be the most toxic of all the sealers on the market, bar none.\textsuperscript{171,172,191} This is discussed further later in the chapter.

Once again one must bear in mind that the resorbability, the dissolvability of all of the zinc oxide sealers, allows them to continue to release their toxic elements and to “break their seal.” Augsburger and Peters allowed 92 cases for up to 6\(\frac{1}{2}\) years after the canals had been overfilled with standard ZOE (Grossman’s-type sealer). “In no recall 50 months or longer did material remain in the periradicular tissues” was their conclusion. In 12 cases, “…careful evaluation of the radiographs of these cases convinced the authors that sealer had also been absorbed from within the canal.”\textsuperscript{192}

Cytotoxic studies on the plastics and resins reveal much the same results as with the zinc oxide-type cements. For example, some have found AH-26, the epoxy resin, the most toxic of the resins tested,\textsuperscript{183} and some found it the least toxic. In the latter study, Diaket (and TubliSeal) showed moderate cytotoxic effect.\textsuperscript{193} In contrast, both studies found that formaldehyde-containing sealers were highly toxic.\textsuperscript{183,193}

Early on, a US Navy study found AH-26 the least toxic, as did a study at Tennessee.\textsuperscript{169,172} Again, Diaket was in between. Swedish dentists reported a “mild response using AH-26.”\textsuperscript{194} In Buenos Aires, AH-26 was found to have a moderate effect and Diaket a markedly toxic effect, both at the end of 1 hour.\textsuperscript{195} AH-26, remember, releases formaldehyde as it sets. Both of these resin sealers were much less toxic, however, than the ZOE control. Statistically significant were the very mild effects of glass ionomer endodontic sealer.\textsuperscript{195}

Newer formulations—AH Plus and Ketac Endo—have had cytotoxic and genotoxic studies done.\textsuperscript{113,123} AH Plus was compared with its original product, AH 26, and in an in vitro test “caused only slight or no cellular injuries” and did not cause any genotoxicity or mutagenicity.\textsuperscript{113} In a study done in Greece, Ketac Endo “proved to be a very biocompatible material, whereas Endion was highly cytotoxic.”\textsuperscript{112}

Subcutaneous Implants. Subcutaneous implants of root canal sealers, to test their toxic effects, are done either by needle injection under the skin of animals, or by incision and actual insertion of the product, either alone or in Teflon tubes or cups. Freshly mixed material may be implanted, allowing it to set in situ, or completely set material may be inserted to judge long-term effects.

The results are what one would expect from the cytotoxicity studies. Eugenol, as all of the essential oils, is a tissue irritant,\textsuperscript{196–198} particularly during initial set.\textsuperscript{104} The long-term results are also not promising.\textsuperscript{199,200} As Tagger and Tagger observed after 2 months, “…the more severe subcutaneous tissue reaction to the zinc oxide-eugenol sealer was probably due to the instability of the material, which slowly disintegrated in contact with tissue moisture.”\textsuperscript{201,202}

At Northwestern University Nogenol proved to be better tolerated initially than TubliSeal or Richert's.
sealer, but at 6 months the effects of TubliSeal were worse and the effects of Richert’s (Kerr’s RCS) and Nogenol were the same. Both contain zinc oxide.

Initial inflammation surrounding implants of SealApex and CRCS, the calcium hydroxide sealers, appears to be resolved at 90 days. Yesilsoy found SealApex caused a less severe inflammation reaction than did CRCS. “Both Grossman’s ZOE sealer and CRCS did not have overall favorable histologic reactions.” Japanese researchers, announcing a new calcium hydroxide sealer, Vitapex, which also contains iodoform and silicone oil, stated that granulation tissue formed around the implanted material and a nidus of calcification then developed within this tissue.

AH-26 elicited “no response at 35 days” in one study and was “well tolerated” at 60 days in another. Without question, N2 and other paraformaldehyde/ZOE cements are consistently the most toxic.

Tissue-implantation ranking of endodontic sealers would again have to list Nogenol, then AH-26, SealApex, and TubliSeal. CRCS, along with the ZOE sealers, would rank higher in toxicity, and the formaldehyde cements rank as unacceptable. A recent comparative study found the formalin-containing cements caused faster and more prolonged nerve inhibition and paresthesia.

Osseous Implant. Surprisingly, sealers implanted directly into bone evoke less inflammatory response than these same cements evoke in soft tissue. From Marseille comes a report of two ZOE sealers implanted into rabbits’ mandibles. At 4 weeks, both sealer implants showed “slight to moderate reactions—no bone formation or bone resorption.” At 12 weeks, there were “slight to very slight reactions—bone formation in direct contact with the sealers—and bone ingrowth into the implant tubes.” Part of the implanted sealer was absorbed, and macrophages were loaded with the sealer.

A US Army group found essentially the same as the French group. When Deemer and Tsaknis overfilled the tubes, “the overfills did not significantly compromise the healing of the rat intraosseous tissue.” However, they noted “the irritating properties of unset Grossman’s sealer.”

In Argentina, Zmener and Dominguez tested glass ionomer cements in dog tubias and stated that at 90 days “the inflammatory picture had resolved with progressive new bone formation.” Again, the paraformaldehyde-containing cements came off second best.

There is not enough evidence to rank cements implanted into bone. However, one must be impressed with the mild-to-stimulating reactions that are reported in bone.

In Vivo Tissue Tolerance Evaluations. There is no question that the ideal method of testing a drug, a substance, or a technique is in vivo in a human subject. Unfortunately, human experimentation is often dangerous, costly, and unethical, and therefore, for the most part, animals are substituted. It can also be said that the closer one rises up the phylum tree to Homo sapiens, the more valid the experiment: Monkeys are better than dogs, and pigs, believe it or not, are better than cats.

In any event, many of the earlier studies were done on rats. This was tiny meticulous root canal therapy compared with the treatment of human beings. Erausquin and Muruzabal, working in Buenos Aires, performed the seminal in vivo research on tissue tolerance to sealers with hundreds of tests on techniques and materials. They concluded that all of the commercial root canal sealers were toxic, causing extensive to moderate tissue damage as soon as they escape through the foramen (Figure 11-13). In all honesty, however, the authors did believe that periapical necrosis may be due in part to an infarct caused by pressure obstruction of the region’s vessels. Necrosis of the periodontal ligament provoked necrosis in the adjacent cementum and alveolar bone as well (Figure 11-14). In the rat, the periodontal ligament regenerates within 7 days if toxic irritation did not continue.

In comparing the various sealers, Erausquin and Muruzabal found that straight ZOE cement was “highly irritating to the periapical tissues and caused necrosis of the bone and cementum.” Inflammation persisted for 2 weeks or more. Finally, the ZOE became encapsulated. Much the same inflammatory reaction was observed at the US National Bureau of Standards when monkey teeth were overfilled with ZOE cement (Figure 11-15).

In a further study, Erausquin and Muruzabal studied other ZOE-based cements. All of the materials, if the canal was overfilled, “showed a tendency to be resorbed” by phagocytes. Grossman’s Sealer and N2 both provoked severe inflammatory reactions, and Rickert’s sealer caused moderate infiltration. The most severe destruction of the alveolar bone, however, was caused by poor débridement and poor filling of the canals. The least reaction was found when the canal was not overfilled.

The tissue reactions to overinstrumentation and overfilling noted by Erausquin and Muruzabal were confirmed by Selzer and colleagues. In all cases, they found immediate periapical inflammation in response to overinstrumentation. When the root canals were filled short of the foramen, the reactions tended to subside.
Figure 11-13  Periradicular tissue reaction to overfilling of rat’s teeth. A, Filling with Procosol Nonstaining Sealer (zinc oxide–eugenol) 1 day postoperatively. Polymorphonuclear leukocytes have invaded even crack in cement. B, Filling with zinc oxide–eugenol cement 4 days postoperatively. Early polymorphonuclear leukocyte infiltration in reaction to material is apparent. Reproduced with permission from Erausquin J, Muruzabal M. Arch Oral Biol 1966;11:373.

Figure 11-14  Periradicular tissue reaction to overfilling with N2 formalin cement, 1 day postoperatively. N2 protruding beyond apical foramen has caused compression of periodontal ligament. Reproduced with permission from Erausquin J, Muruzabal M. Arch Oral Biol 1966;11:373.
within 3 months and complete repair eventually took place. In contrast, the teeth with overfilled root canals exhibited persistent chronic inflammatory responses. There was also a greater tendency toward epithelial proliferation and cyst formation in the overfilled group. Another South American group reported on dog peri-radicular specimens overfilled with SealApex, CRCS, and ZOE. All responded with chronic inflammation.

The least irritating of the cements tested by Erausquin and Muruzabal were Diaket and AH-26. Following overfilling with these sealers, the "inflammation was generally very mild." Diaket, which showed a marked tendency to be projected beyond the apex, became readily encapsulated (Figure 11-16). AH-26, on the other hand, was resorbed instead (Figure 11-17). The researchers observed, "when a foreign body is not too irritating, it becomes either resorbed or encapsulated by the body" (see Figure 11-17). Both of these processes occurred in teeth filled with Diaket and AH-26.

More recently, Norwegian researchers tested AH26 against Endomethasone, Kloropercha, and ZOE. At 6 months they concluded that "the periradicular reaction to the endodontic procedures and to the materials was limited." On the other hand, the University of Connecticut group found long-term (2 or 3 years) differences, ranking AH26 as a mild irritant, ZOE as moderate, and Kloropercha as severe.

One must remember that gutta-percha points themselves can be a periradicular tissue irritant, as well as an allergen. Moreover, solvents such as chloroform, eucalyptol, and xylol can also act as irritants.

One must conclude that periradicular tissue reaction to all of the cements will at first be inflammatory, but as the cements reach their final set, cellular repair takes place unless the cement continues to break down, releasing one or more of its toxic components.

In retrospect, one must not overlook the casual observation made by the group at Tufts University: "There

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**Figure 11-15** Monkey study, periradicular area, 2 months after ZOE Grossman Sealer overfill (Gs). A. Acute inflammation with giant cells (Gc) and necrotic bone sequestration (SEQ). B. Marked acute inflammation. Polymorphonuclear leukocytes predominate. Reproduced with permission from Hong YC et al.
were several small well-encapsulated areas of mild inflammation that seemed to be associated with apical ramifications that were not cleaned and that contained necrotic debris.\textsuperscript{224} Although arborization of the pulp at the periapex is more apt to happen in dogs and monkeys than in humans, one cannot blink away the fact that a final filling is no better than its preparation, and if necrotic and infected dentin and debris are left in place, the case stands a greater chance of eventual failure.

One can summarize the discussion on root canal sealers by repeating a statement made more than 100 years ago by Dr. A. E. Webster of Toronto: “It would seem that the dental profession has not yet decided upon a universal root canal filling material.”\textsuperscript{228}

The N2/Sargenti Controversy. The term N2, as used here, is a code word for formaldehyde-containing endodontic cements. Actually, formaldehyde is a gas, whereas the forms used in dentistry are variations of formalin, the aqueous solution, or paraformaldehyde, a white crystalline polymer.

N2 itself contains 6.5% paraformaldehyde, as does its US counterpart, RC2B. Other paraformaldehyde/formalin-containing cements, popular in Europe, such as Endomethasone, Riebler’s Paste, or the SPAD products, may contain more or less than 6.5% formaldehyde. All of them are toxic.

Legal Status in the United States. The controversy swirling around N2 and RC2B deserves special discussion. The use of these cements, recommended primarily by members of the American Endodontic Society (a group of general dentists), has become a cause célèbre, pitting endodontist against generalist, academician against practitioner. Along with these cements comes a method of practice—the so-called “Sargenti Method.”

The method and Sargenti have been imported from Switzerland, but the N2 cement was barred at the borders by the FDA in about 1980. To evade the importation ban, disciples of Sargenti developed their own (and very similar) cement powder, RC2B. This was also banned under an FDA order that stated that the Agency “will take immediate regulatory action to stop the commercial manufacture and distribution of N2 type drugs” (R. J. Crout, personal communication, June 19, 1980).
The FDA pointed out, however, that they do not regulate the practice of dentistry and that “an endodontist or a ‘general dentist’ may use the N2 product themselves or arrange to have a supply obtained by prescription for that individual patient.” The dentist, however, should recognize that he is responsible for the consequences of the use of N2 within his practice (R. J. Crout, personal communication, June 19, 1980).

The basis for these actions and this warning is the statement, “The Food and Drug Administration has long held, and still does, that N2 has not been demonstrated to be safe and effective for use in root canal therapy” (R. J. Crout, personal communication, June 19, 1980).

As late as 1992, the FDA was still warning dentists that “…the N2 material is considered to be an unapproved new drug—and may not legally be imported or distributed in interstate commerce…” and in 1993 an advisory panel to the FDA rejected new drug application No. 19-182 submitted by N2 Products Corporation of Levittown, Pennsylvania.

This action follows on the heels of jury awards of $250,000 in one case and $280,000 in another to patients injured by overextension of N2 into the periradicular tissues of two female patients. 

Paralegally, the Council on Dental Therapeutics of the American Dental Association issued a resolution against paraformaldehyde sealers that concluded “that the FDA has not approved any products with this formulation, [so] the Council cannot recommend the use of these products at this time.” This report buttressed two previous negative pronouncements by Council in 1977 and 1987.

At the state level, the Florida Board of Dentistry has banned “Sargenti cement, charging that use of the filling material falls short of the minimum standard of (dental) care in Florida.” This action was precipitated by a number of lawsuits, including an out-of-court settlement for $1,000,000 to a woman horribly disfigured after paraformaldehyde paste was misused (R. Uchin, personal communication, September 22, 1992).

The American Association of Endodontists has also issued a position statement condemning the use of paraformaldehyde sealers.

Paraformaldehyde Toxicity. As initially compounded, N2 was a ZOE cement containing 6.5% paraformaldehyde as well as some lead and mercury salts. Concern over lead and mercury transport via the bloodstream to vital organs forced the American producers of the N2 lookalike, RC2B, to drop the heavy metals. However, in no way would they reduce the toxic paraformaldehyde from the formula. A myriad of damaging research papers—in vitro, in vivo, clinical—denouncing these products, has been published in the last 25 years from all over the world. Pitt-Ford found, for example, that N2 and Endomethasone caused a universal ankylosis and root resorption of dogs’ teeth filled, but not overfilled, with these toxic products.

The two most definitive in vivo studies on the effects of paraformaldehyde were done at Indiana University. In a 1-month study using monkeys, researchers found apical periodontitis around 7 of 9 apices and “a granuloma with considerable loss of bone around another” when RC2B was applied to 10 inflamed pulps, as recommended by Sargenti. The “treated” pulps were in no better shape than the untreated inflamed controls. At 6 months and 1 year, severe periradicular inflammation with liquefaction necrosis developed after RC2B was applied to coronal pulps with pulpitis. None of the control teeth had periradicular inflammation. When RC2B was used to fill well-prepared root canals, previously allowed to become necrotic, the results were even more overwhelming: osteomyelitis at 6 months and abscess formation, even cyst formation, within massive periradicular lesions at 1 year (Figure 11-18). The cases “treated” with RC2B were no better, or were worse, than the necrotic canal cases left open to salivary bacteria (Figure 11-19). Around a fragment of RC2B found in the tissue, advanced inflammation, necrosis, and even osteomyelitis were present (Figure 11-20). At the National Bureau of Standards, much the same destruction was found (Figure 11-21).

The most important constituent in any of these cements (N2, RC2B, Endomethasone, SPAD) is the paraformaldehyde, according to their proponents. As a matter of fact, Sargenti allows for the removal of any ingredient from the powder except paraformaldehyde. Unfortunately, it is this toxic product, unique to these cements, that causes the destruction. It is its release, as the sealers are resorbed, that allows for their destructive behavior. Neiburger reported a case showing radiographic disappearance of RC2B from the periapex within 5 weeks. The Indiana group noted resorption of RC2B within 1 month.

Nerve Damage from Paraformaldehyde. It has long been recommended by its proponents that N2 be placed in the canal with a fast-spinning Lentulo spiral. This is a perfectly reasonable approach, but one has to know when enough is enough. Sargenti warns that, without great care, overfilling is likely with this technique. He does not say, however, how very damaging such overextension will be. Periradicular destruction was shown in the Indiana studies. Also, “the ADA Council on Dental Therapeutics and Devices has
Figure 11-18 N2/RC2B formalin cement study. A. Control specimen, pulp necrosis 3 months standing. Apical granuloma with epithelial proliferation. B. Osteomyelitis 6 months after treatment of necrotic canal with RC2B. Areas of necrotic bone within dense inflammatory infiltrate. C. Apical cyst developing 6 months after treatment of necrotic canal with RC2B. Note epithelial lining within dense inflammatory infiltrate. Reproduced with permission from Newton CW et al.258

Figure 11-19 One year after treatment of necrotic canal with RC2B, large granuloma and strands of proliferating epithelium are apparent. Reproduced with permission from Newton CW et al.258

Figure 11-20 Overfill with RC2B. After 1 year, severe inflammation with necrosis is apparent. Adjacent bone was osteomyelitic. Reproduced with permission from Newton CW et al.258
specifically cautioned dentists regarding severe postoperative complications that not infrequently accompany these [Sargenti] pastes when inadvertently extruded past the apex.259

Endodontic overfillings are no surprise to anyone who does root canal therapy. But, despite Sargenti’s warning to his followers not to overfill, 15% of the 806 cases submitted for “Fellowship” status in the American Endodontic Society demonstrated overfilling.260

Reaction to the physical and chemical trauma of paraformaldehyde periradically can be so severe that immediate apical trephination is highly recommended by the Sargenti proponents. For this exigency, the dentist is supplied with a “Fistulator” to trephine to the periapex to relieve the pressure and pain that might follow treatment with N2 (Figure 11-22). A survey conducted by the American Endodontic Society of 48,134 cases treated by 411 dentists shows 9,910 cases of trephination.148 This figure indicates that the method was necessary 20.5% of the time when N2 or RC2B was used.

An even greater problem occurs when N2 or RC2B is forced into the maxillary sinus or the mandibular canal. A number of cases of persisting paresthesia, primarily of the inferior alveolar nerve, have been reported following the misuse of paraformaldehyde cements.262–268 That this accident can happen with any root canal sealer cannot be denied.269–273 However, as Weichman, a lawyer-endodontist, points out, paresthesia from other cements gradually fades away (J. Weichman, personal communication, June 2, 1982). Paresthesia from paraformaldehyde, on the other hand (since the nerve is literally embalmed), may remain forever (Figure 11-23). From Ankara, Turkey, a comparative study of the neurotoxic effects of sealers revealed that formalin cements caused a faster and more prolonged inhibitory effect on nerve transmission, as well as paresthesia, than did other tested sealers.207

After reviewing the literature in 1988, Brodin noted that more than 40 cases of neurotoxicity caused by overfilling had been reported and that “sealers containing formaldehyde were irreversible unless surgical treatment was performed (22 of 25 cases).”274 Since then, a number of cases involving N2, RC2B, SPAD, and Endomethasone have been reported.275–278
The tragedy of overfilling into the mandibular canal, especially with such toxic materials, relates to a misconception of the size of the pulp. Dentists spin more and more material into the canal, far more than it takes to fill the space. Fanibunda points out that the average pulp space of a maxillary central incisor is the size of a drop of water. This is the entire pulpal space, crown and root. The root canal is only a small portion of this volume. A mandibular molar pulp space would hold only four drops, pulp chamber included. Enough is enough!

In summation, one might ask, “Why isn’t the Sargenti method taught in American dental schools?” and “Why does the Sargenti method raise so many troublesome questions?” The answer to both questions is rather simple. The Sargenti method has become a cult and, like most cults, is based more on testimonials than on facts. The second reason, of course, relates to the toxic components of the material that the cult insists are necessary to success.

These reasons, along with the countless lawsuits and out-of-court settlements centering around the technique and cements, keep many from joining while many desert the ranks. Pitt-Ford reports the same turnaround in Britain. “N2 is now seldom used—probably because of the numerous reports of its adverse effects and the fact that it is not recommended by dental schools.”

Sargenti himself indicated a double standard of endodontic treatment when he publicly stated, “If I had endodontic problems myself, and if I wished to have an exact endodontic treatment, I should certainly ask Dr. Herbert Schilder to treat me.”

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**PREPARATION FOR OBTURATION**

To this point, a good deal has been said about the materials that go into the canal: their efficacy, their toxicity, their resorbability. But as the old adage goes, “What comes out of the canal is much more important than what goes into it.” For this reason, great emphasis has been placed on radicular preparation and débridement—“biochemical preparation” à la Grossman or “cleaning and shaping” per Schilder.

Even if the canal space is perfectly débrided and is free of all debris and bacteria, what of the dentin walls left? Are they free of bacteria? Are they prepared to adhere to the obturating material or will the sealants chemically adhere to them? One look at these so-called “glassy smooth” walls in an electron micrograph leaves one in doubt (Figure 11-24, A). The smear layer may also be loaded with bacteria that penetrate out of the layer into the dentinal tubules (Figure 11-24, B).

**The Dentin Interface**

“Many of our currently accepted methods of chemical preparation are inadequate in producing a debris-free canal.” In addition to the pulp tissue debris and bacteria, several papers have described a sludge or a “smear layer” left attached to the inner canal walls, obstructing the dentinal tubules. Goldman and colleagues have demonstrated that the smear layer, created by instrumentation, is primarily calcific (inorganic) in nature.

However, there is also an organic component, undoubtedly reflecting the chemical composition of dentin: the greater inorganic and lesser organic component of the smear layer, as well as necrotic tissue and bacteria. Remember that the smear layer is subject to early dissolution, and if apical leakage occurs, the loss of the smear layer will provide an easy ingress for fluid and bacteria.

There is no direct evidence that the smear layer must be removed. On the other hand, Yamada et al. state that a case can be made for its removal: “For instance, it may interfere with the adaptation of filling materials to the canal wall by imposing an additional interface.” At Aristotle University in Greece, researchers reported that “smear layer removal resulted in a statistically significant reduction in microleakage when AH26 was used as a sealer. However, the presence or absence of the smear layer had no significant effect on the sealing ability of Roth 811.” In another vein, Yamada et al. went on to state, “In addition, opening all the tubules can perhaps provide a better seal by allowing sealer or filling material to penetrate” the dentin.
Gutmann, for example, has noted that thermoplasticized gutta-percha, and of course sealer, penetrates well into patent tubules freed of the smear layer.284 An Athens research group also pointed out the importance of using ethylenediaminetetraacetic acid (EDTA) to remove any calcium hydroxide clinging to the dentin walls and thus blocking the tubuli.293

Opening the tubuli makes great sense. If chemical adhesion between the dentin and sealers, pastes, cements, or plastics cannot be achieved, then why not a mechanical lock? The material will flow or be forced back into the empty dentin tubules, gripping like tentacles and forever resisting displacement (see Figure 11-12, B).

Opening the oriﬁces of the dental tubules can be achieved with acids as shown by Loel,294 Tidmarsh,295 Waymen and colleagues,296 and Pashley and colleagues,297 using various strengths of citric, phosphoric, or lactic acid (Figure 11-25), or by others using EDTA as chelators.288,298–308 Calt and Serper, using EDTA, also pointed out the importance of removing calcium hydroxide dressing from the dentinal walls to open the tubuli.309

More recently, workers at Tufts University found that “…the combined use of 10 cc of 17% EDTA (pH.7.5) followed by 10 cc of 5.25% sodium hypochlorite (NaOCl) produced the best overall results in removing both superficial debris and the smeared

Figure 11-24  A, Scanning electron micrograph view of dentin smear layer. Top half of photo is smear. Lower half of cut surface shows occluded tubuli. B, Smear layer (left) after canal preparation. Note packed debris and extensions into tubuli. (Courtesy of Drs. Martin Bränström and James L. Gutmann.)

Figure 11-25  Scanning electron microscope view of smear layer etched away and tubuli opened by a 2-minute application of 37% phosphoric acid. A similar effect can be achieved in 5 to 15 seconds. (Courtesy of Dr. Martin Bränström.)
layer. A group in Turkey achieved a similar result using 17\% EDTA combined with 5\% ethylenediamine, an organic solvent. In arriving at these conclusions, they had tested saline, citric acid (25\%), and various combinations of sodium hypochlorite and EDTA. The chelator (EDTA) was very efficient in removing the inorganic (calcium salts) from the smear layer all the way to the apical third. But the sodium hypochlorite was needed to dissolve and douche away the organic (dentin matrix, pulp remnants, necrotic and bacterial debris) constituents of the smear. It goes without saying that sodium hypochlorite irrigation was used between instrument sizes during canal preparation.

Recent research reinforces the evidence that smear removal is efficacious. One must bear in mind Rawlinson’s findings, however, that 1 minute of ultrasonic irrigation with citric acid and sodium hypochlorite did not remove all of the smear layer in the important apical third. The Minnesota group recommended 3 minutes of irrigation, each with EDTA and sodium hypochlorite. This improved the bond with AH-26. The original group at Tufts used 10 cc each of EDTA and sodium hypochlorite to improve the bond with Bis GMA resin. Others reported improved bonding with ZOE, SealApex, AH-26, TubliSeal, and Diaket.

With this final smear layer removal, the dentin interface needs only thorough drying to be ready to receive the obturating materials.

METHODS OF OBTURATING THE ROOT CANAL SPACE

Over the years, countless ways and materials have been developed to fill prepared canals. Again, Webster noted over 100 years ago, “...it would seem that the dental profession has not yet decided upon a universal root canal filling material.” At least today’s attempts seem a bit more sophisticated than the “cotton, raw cotton, and cotton and gutta-percha,” noted by Webster. On the other hand, he favorably recommended warm gutta-percha and vertical compaction, but also noted that warmed gutta-percha shrinks when it cools.

Today, most root canals are being filled with gutta-percha and sealers. The methods vary by the direction of the compaction (lateral or vertical) and/or the temperature of the gutta-percha, either cold or warm (plasticized).

These are the two basic procedures: lateral compaction of cold gutta-percha or vertical compaction of warmed gutta-percha. Other methods are variations of warmed gutta-percha.

The methods are listed as follows:

I. Solid Core Gutta-Percha with Sealants
   A. Cold gutta-percha points
      1. Lateral compaction
      2. Variations of lateral compaction
   B. Chemically plasticized cold gutta-percha
      1. Essential oils and solvents
         a. Eucalyptol
         b. Chloroform
         c. Halothane
   C. Canal-warmed gutta-percha
      1. Vertical compaction
      2. System B compaction
      3. Sectional compaction
      4. Lateral/vertical compaction
         a. Endotec II
      5. Thermomechanical compaction
         a. Microseal System, TLC, Engine-Plugger, and Maillefer Condenser
         b. Hybrid Technique
         c. J.S.-Quick-Fill
         d. Ultrasonic plasticizing
   D. Thermoplasticized gutta-percha
      1. Syringe insertion
         a. Obtura
         b. Inject-R-Fill, backfill
      2. Solid-core carrier insertion
         a. Thermafil and Densfil
         b. Soft Core and Three Dee GP
         c. Silver points

II. Apical-Third Filling
   A. Lightspeed Simplifill
B. Dentin-chip
C. Calcium hydroxide

III. Injection or “Spiral” Filling
   A. Cements
   B. Pastes
   C. Plastics
   D. Calcium phosphate

The “compleat” clinician will master many, if not all, of these techniques. The rigidity of being “married” to one particular method or material limits not only case acceptance but success as well.

Lateral Compaction of Cold Gutta-percha

The lateral compaction of cold gutta-percha points with sealer is the technique most commonly taught in dental schools and used by practitioners and has long been the standard against which other methods of canal obturation have been judged. This technique encompasses first placing a sealer lining in the canal, followed by a measured primary point, that in turn is compacted laterally by a plugger-like tapering spreader used with vertical pressure, to make room for additional accessory points (Figure 11-27). The final mass of points is severed at the canal’s coronal orifice with a hot instrument, and final vertical compaction is done with a large plugger. If executed correctly, solid canal obturation will totally reflect the shape and diversions of the properly prepared canal network (Figure 11-28).

Lateral condensation can only be achieved if certain criteria are fulfilled in canal preparation and instrument selection. The final canal shape should be a continuous taper, approaching parallel in the apical area, that matches the taper of the spreader/plugger. The
spreader must reach within 1.0 to 2.0 mm of the working length (Figure 11-29), an apical stop must be created to resist apically directed condensation, and the accessory gutta-percha cones must be smaller in diameter than the spreader/plugger (see Figure 11-27). Lateral condensation is not the technique of choice in preparations that cannot meet these criteria and not all canals can be shaped to meet these criteria. Before embarking on the filling process, however, several important steps in preparation must first be completed: spreader size determination, primary point and accessory point size determination, drying the canal, and mixing and placement of the sealer.

**Spreader Size Determination.** Before trying in the trial point, it is mandatory to fit the spreader to reach to within 1.0 to 2.0 mm of the true working length and to match the taper of the preparation. Spreaders are available that have been numbered to match the instrument size (Figure 11-30). Therefore, a spreader of the same apical instrument size or one size larger is chosen so that it reaches to within 1.0 to 2.0 mm but will not penetrate the apical orifice. Not all canals can be shaped to fit the variety of lengths and tapers of available spreaders. This technique requires a knowledge and understanding of the size and shapes created by different cleaning and shaping instruments, as well as of the spreaders. If the spreader taper is greater than the canal taper, there will be an apically directed force during condensation that can result in overfill. If the taper of the canal is greater than that of the spreader, there is a tendency to displace the master cone coronally during condensation.

Allison and his colleagues at the University of Georgia vividly demonstrated the importance of deep spreader penetration. They also pointed out that “the most important factor affecting the quality of the apical seal is the shape of the canal,” a true tapered preparation that would allow the spreader to nearly reach the apical terminus. Canals so treated had virtually no apical percolation310 (Figure 11-31). Spreaders should always be fit into an empty canal (Figure 11-32) to ensure that the force is absorbed by the gutta-percha and not the canal walls, which could result in root fracture. After the gutta-percha is placed, and the spreader is inserted but does not reach the premeasured depth, condensation of the gutta-percha will occur laterally.
from a force directed from the canal walls toward the gutta-percha.

A rubber stop should be placed on the shaft of the spreader to mark true working length minus 1 mm. It is then set aside for immediate use.

**Primary Point Size Determination.** Gutta-percha points have been standardized in size and shape to match the standardized instrument sizes. They have even been color-coded to match the instrument’s color.

Conventional sized cones are too tapered with a bulk of material in the coronal area that would resist penetration of the spreader. However, nothing should be left to chance; the primary point should be selected to match the size of the last instrument used at the apex and should be tested in place and confirmed radiographically.

Gutta-percha comes sterilized from the package or it may be sterilized with a germicide for 5 minutes in sodium hypochlorite (5.25%), hydrogen peroxide (3%), or chlorhexidine (2%).\textsuperscript{311,313} Gutta-percha itself does not readily support bacterial growth.\textsuperscript{313}

The four methods used to determine the proper fit of the primary point are as follows: (1) visual test, (2) tactile test, (3) patient response, and (4) radiographic test.

**Visual Test.** To test the point visually, it should be measured and grasped with cotton pliers at a position within 1 mm short of the prepared length of the canal. The point is then carried into the canal until the cotton pliers touch the external reference point of the tooth. This master point should always be tried in a wet canal to simulate the lubrication of the sealer. If the working length of the tooth is correct and the point goes completely to position, the visual test has been passed unless the point can be pushed beyond this position. This can be determined by grasping 1 mm farther back on the point and attempting to push it apically. If the point can be pushed to the root end, it might well be pushed beyond into the tissue. Either the foramen was originally large or it has been perforated. If the point can be extended beyond the apex, the next larger size point should be tried. If this larger point does not go into place, the original point may be used by cutting pieces off the tip. Each time the tip is cut back 1 mm, the diameter becomes larger by approximately .02 mm. By trial and error, the point is retriied in the canal until it goes to the correct position.

Jacobsen has shown the distortion in the point that ensues if scissors are used to “snip” off the tip. He shows that distortion can be avoided by “rolling the point back and forth on a sterile glass plate and applying gentle pressure with a No. 15 scalpel blade”\textsuperscript{314} (Figure 11-33). The main reason for trial point testing is to be sure the point extends far enough for total obturation but will not extend beyond the apical foramen. The termination of the point within 1 mm short of the prepared length provides for apical movement from the vertical forces of compaction aided by lubrication from the sealant. One cannot predictably rely on the spreader to seat the master point if it has not been confirmed to the desired position. If everything is right, the solid-core material is sealed exactly into the prepared space, not pushed beyond into an overfill.
Tactile Test. The second method of testing the trial point is by tactile sensation and will determine whether the point tightly fits the canal. In the event the apical 3 to 4 mm of the canal have been prepared with near parallel walls (in contrast to a continuous taper), some degree of force should be required to seat the point, and, once it is in position, a pulling force should be required to dislodge it. This is known as “tugback.” Allison and the Georgia group have shown, however, that significant tugback in primary gutta-percha point placement is not essential to ensure a proper root canal seal.315 Again, if the point is loose in the canal, the next larger size point should be tried, or the method of cutting segments from the tip of the initial point, followed by trial and error positioning, should be used. Care must be taken not to force the sharp tip of a point through the foramen.

Patient Response. Patients who are not anesthetized during the treatment of a nonvital pulp or at the second appointment of a vital pulp may feel the gutta-percha penetrate the foramen. Adjustments can then be made until it is completely comfortable. This is a good test when the position of the foramen does not appear to be accurately determined by the radiograph or by tactile sensation. Pulp remnants from a short preparation will cause a sensation of much greater intensity than periapical tissue. Granulation tissue may not produce any sensation at all.

Radiograph Test. After the visual and tactile tests for the trial point have been completed, its position must be checked by the final test—the radiograph (Figure 11-34). The film must show the point extending to within 1 mm from the tip of the preparation. Radiographic adaptation is a better criterion of success than either the visual or tactile method.315

The trial point radiograph presents the final opportunity to check all of the operative steps of therapy completed to date. It will show whether the working length of the tooth was correct, whether instrumentation followed the curve of the canal, and whether a perforation developed. It will also, of course, show the relationship of the initial filling point to the preparation.

Occasionally the radiograph shows the point forced well beyond the apex. If this is the case, an incorrect working length has been used during instrumentation, and the operator may have wondered why the patient complained of discomfort. The overextended point

Figure 11-33 Length-adjusted gutta-percha points. A, Size 30 gutta-percha point shortened with scissors. Distortion prevents proper placement at apical seal. B, Size 30 gutta-percha point trimmed with scalpel, allowing more perfect apical fit. Reproduced with permission from Jacobsen EL.314

Figure 11-34 Trial point radiograph. Confirmation film indicates the primary point should be advanced by another 2.0 mm by either enlarging one more size or trying the next smaller point. (Courtesy of Dr. Carl W. Newton.)
should always be shortened from the fine end and then carefully returned to proper position. It should never be just pulled back to a new working length, in which case it would be loose in the canal. In this new position, it should again pass the tactile and radiographic tests of trial points. It should never be manipulated so that it just appears to fit in the film. It must fit tightly and come to a dead stop.

Sometimes the initial point will not go completely into place even though it is the same number as the last enlarging instrument. This condition may arise because (1) the enlarging instrument was not used to its fullest extent, (2) there was a larger than standard deviation between the sizes of instruments and gutta-percha, (3) debris remains or was dislodged into the canal, or (4) a ledge exists in the canal on which the point is catching.

In any case, the problem can be solved by one of two methods: selecting a new file of the same number and re-instrumenting the canal to full working length until the file is loose in the canal, or selecting a smaller size gutta-percha point. Trial and error will determine when the point is seated. If a ledge has been developed in the canal wall, it must be removed by the method suggested in chapter 10.

Preparation of the Initial Point. After the initial point has passed the trial point tests, it should be removed with cotton pliers that scar the soft point or snipped with the scissors at the reference point (Figure 11-35).

Drying the Canal. While preparations are being made to cement the filling point, an absorbent paper point should be placed in the canal to absorb moisture or blood that might accumulate. Larger paper points are followed by smaller paper points until full length is achieved. To determine the presence of moisture in the canal, one must remove the absorbent point and draw the tip along the surface of the rubber dam. If the point is moist, it will leave a mark as it removes the powder from the dam. When this procedure has been repeated with fresh points that no longer streak the dam, the final paper point is left in place to be removed just as the sealer is to be introduced. Any bleeding should be stopped, the blood irrigated from the canal, and care taken to avoid penetrating beyond the apex with the final paper point. Excess moisture or blood may affect the properties of the sealer, although fluids may be completely displaced during condensation and not affect the seal.

Mixing and Placement of the Sealer. Mixing. A sterile slab and spatula are removed from the instrument case or are sterilized by wiping with a gauze sponge soaked in germicide and dried with a sterile sponge. One or two drops of liquid are used and the cement is mixed according to the manufacturer’s directions. The cement should be creamy in consistency but quite heavy, and should string out at least an inch when the spatula is lifted from the mix (Figure 11-36).

Benatti and colleagues tested five commercially available sealers and concluded that ideal consistency is achieved when the mixture can be held for 10 seconds on an inverted spatula without dropping off and will stretch between the slab and spatula 2 cm before breaking. Ideal consistency permits ample clinical working time and minimal dimensional change.

Sealer should not be mixed too thin, but on the other hand, it must not be so viscous that it will not flow between the gutta-percha points or penetrate accessory and lateral canals or the dentin tubules.

Placement. Sealer can be placed in abundance to ensure thorough canal wall contact because the tech-
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Root canal cement/sealer may be placed in a number of ways. Some clinicians “pump” the sealer into the canal with a gutta-percha point. Some carry it in on a file or reamer, which is twirled counterclockwise, pumped up and down, and wiped against all the walls. Some use rotary or spiral paste fillers turned clockwise in one’s fingers or very slowly in a handpiece (Figure 11-37).

Using rotary or spiral paste fillers is not without danger. If powered by a handpiece, they can be easily locked in the canal and snapped off (Figure 11-38). Twirling them in the fingers is safer, and Lentulo spirals are now being made with regular instrument handles (Dentsply/Maillefer; Tulsa, Okla. and Switzerland).

Another problem encountered in using rotary-powered Lentulo spirals comes from “whipping up” the cement in the canal and causing it to set prematurely. The primary point will then not go into place. Investigators in Scotland also found that the powered Lentulo spiral consistently caused sealer extrusion.319

A more recent method is to place the cement with an ultrasonic file—run without fluid coolant, of course.319 A US Army group found ultrasonic endodontic sealer placement significantly superior \( (p = .001) \) to hand reamer placement. They were pleased to see proper coverage to the apical orifice but not beyond. Lateral and accessory canals were filled as well. As with the Lentulo spiral-placement, they found that ZOE cement set within a few seconds when ultrasonically spatulated in the canal. Heat generated by ultrasonics can acceler-

Figure 11-36 Root canal cement should be mixed to thick, creamy consistency, which may be strung off slab for 1 inch.

Figure 11-37 Rotary paste fillers made for contra-angle handpiece can also be rotated clockwise by finger action. Used for placing initial sealer with solid core root fillings or completely filling the canal with paste filling. A, Produits Dentaires, Switzerland. B, Micro Mega, France. C, Hawes-Neos, Switzerland. The Hawes-Neos type is preferred because of its stronger rectangular blade. (Courtesy of Dr. Frederick Harty, London.)

Figure 11-38 Lentulo spiral fractured in distal canal of lower molar. Careful observation reveals spiral also fractured in mesial canal and a cervical perforation and a broken reamer in mesial gingiva. (Retouched for clarity.)
ate ZOE sealers. However, they used AH-26 successfully.\textsuperscript{320,321} A San Antonio group also found the Lentulo to be the most efficient in coating the walls; 90.2%, compared with using a K-file at 76.4% or using a gutta-percha point at 56.4%. They suggested that complete coverage may not be possible.\textsuperscript{322}

**Placement of the Master Point.** The premeasured primary (or master, or initial) point is now coated with cement (Figure 11-39) and slowly moved to full working length. The sealer acts as a lubricant. The patient may experience some minor discomfort from this procedure as air or sealer is evacuated from the canal through the foramen. If the resistance form has been correctly prepared so that a “minimal opening” exists at the foramen, no more than, and usually not as much as, a tiny puff of cement will be forced from the apex.

It is frequently asked why the well-fitting initial point does not force a great quantity of cement through the apical foramen. The answer lies in the tapered shape of the point and corresponding shape of the canal. One should not think of the point as a plunger, for a plunger has straight walls. The tapered point does not actually touch the walls of the prepared canal until just that moment when it reaches its final seat. It will thus not force quantities of cement ahead of it, but will rather displace cement coronally as it is slowly moved into position. Thus one need not fear that there is an excessive amount of cement in the canal prior to placement of the point.

**Multiple-Point Obturation with Lateral Compaction**

When the fit of the cemented primary point is ensured (Figure 11-40, A), the butt end, extending into the coronal cavity, should be removed with a hot instrument or scissors to allow room for visualization and the spreader that is to follow.

The premeasured spreader is then introduced into the canal alongside the primary point, and with a rotary vertical motion is slowly moved apically to full penetration, marked on the shaft with a silicone stop. (Figure 11-40, B). It is the wedging force that occurs between the canal walls toward the gutta-percha that results in deformation and molding of the gutta-percha to the opposite canal walls (Figure 11-41). There is no need to apply a lateral force to the spreader. Weine recommends that the initial spreader be left in place a full minute to allow the primary gutta-percha time to reconform to this pressure.\textsuperscript{323} One must know that, along with the lateral force of spreading, a vertical force, albeit less, is also exerted.\textsuperscript{315,324} If the spreader does not reach the premeasured length within the apical 1 mm, firm apical pressure can be applied with the knowledge that the gutta-percha, and not the tooth, is absorbing the force that could result in fracture (Figure 11-42). If full penetration is still not achieved, a spreader that is a size smaller can be used, which will bind apically to the previous spreader. The master point may appear to elongate slightly coronally as it stretches to plasticity at the point of condensation. Remember, adequate condensation does not occur unless the initial spreader reaches length.

The spreader is then removed with the same reciprocating motion and is immediately followed by the first auxiliary point inserted to the full depth of the space left by the spreader (Figure 11-40, C). Selecting auxiliary cones that are the same size or smaller in diameter or taper than the spreader requires a knowledge of ISO Standards for conventional gutta-percha cones and manufacturer’s specifications for the chosen spreaders. Spreader penetration that is limited by a bulk of gutta-percha in the midroot area does not result in adequate condensation in the important apical area. Some clinicians use heat at this point to soften the bulk of gutta-percha and allow easier penetration through the coronal area. This point is followed by more spreading (Figure 11-40, D) and more points (Figure 11-40, E), more spreading and more points, until the entire root cavity is filled.

To ensure a cohesive filling, additional sealer should be added with each point as a lubricant to facilitate full penetration. Obturation is considered complete when the spreader can no longer penetrate the filling mass beyond the cervical line.

At this time the protruding points are severed at the orifice of the canal with a hot instrument (Figure 11-40, F). Vertical compaction with a large plugger will then ensure the tightest possible compression of the
gutta-percha mass and provide a more effective seal against coronal leakage. All of the sealer and gutta-percha should then be removed from the pulp chamber and a final radiograph taken (Figure 11-43). After an intraorifice barrier is placed, either a final or temporary coronal filling should follow.

If one follows this technique—lateral compaction of cold gutta-percha points—a number of questions may arise: What size and style of spreader should be used? Which accessory gutta-percha points match the spreaders in size and taper? How much force should be used with a spreader? Can vertical fractures occur?

**Spreader Size and Taper.** Spreaders are supplied in multiple shapes, sizes, lengths, and tapers, including hand spreaders with a bent binangle shaft, and small straight finger spreaders. Nickel titanium has also improved flexibility and has been shown to penetrate to significantly greater depths than does stainless steel in curved canals.

In 1955 Ingle drew attention to the discrepancy in spreader sizes as well as matching gutta-percha points. After 35 years of confusion, the ISO/ADA endodontic standardization committee, in 1990, recommended that spreaders and pluggers be modeled after the accepted standardized instruments and gutta-percha points, No. 15-45 for spreaders and No. 15-140 for pluggers.

This new attempt to bring order out of chaos would abandon the old confusing numbering systems (1-10, D-11, D-11T, ABCD, XF, FF, MF, F, FM, M, etc) and recommend that all spreaders, pluggers, and auxiliary

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**Figure 11-40** Lateral compaction, multiple-point filling procedure. Spreader has previously been tested to reach to within 1.0 mm of apical constriction. Thin layer of sealer lines canal walls, tip of point is coated with cement. A, Primary point is carried fully to place, to within 1.0 mm of “apical stop.” Excess in crown is severed at cervical with hot instrument. B, Spreader (arrow) is inserted to full depth, allowed to remain 1 full minute as gutta-percha is compacted laterally and somewhat apically. C, Spreader is removed by rotation and immediately replaced by first auxiliary point previously dipped in sealer. D, Spreader (arrow) is returned to canal to laterally compact mass of filling. Secondary vertical compaction seals apical foramen. E, Spreader is again removed, followed by matching auxiliary point. Process continues until canal is totally obturated. F, All excess gutta-percha and sealer are removed from crown to below free gingival level. Vertical compaction completes root filling. After an intraorifice barrier is placed, a permanent restoration with adhesives is placed in crown.
gutta-percha points meet the ISO/ADA specification. More recent developments in non-ISO/ADA specification for the variable taper (.04/.06 taper instruments) will require more understanding of the final dimensions of the preparation for spreader selection. Rotary instrumentation with these instruments offers the possibility of a very standardized preparation with known diameter and taper at every level of the canal.

A number of investigations that attempted to untangle the problem would become moot if standardization went into effect. In 1991, Hartwell and his associates forwarded the same opinion regarding standardization that was voiced by Ingle 36 years before. In keeping with the trend toward standardization, Martin has introduced a set of calibrated hand spreaders and pluggers to match in size and taper the ISO/ADA instrument standardization. The instruments, with color-coded handles, range in size from No. 20 through No. 60 M Series (Figure 11-44) (Dentsply/Maillefer; Tulsa, Okla.). The space made by these spreaders may be filled with gutta-percha points (again color-coded) of the same number.

Stress and Fractures from Lateral Compaction. Hatton and his associates found they could adequately seal root canals with as little as 1 kg of spreader pressure. They applied up to 2.5 kg and suggested that excessive forces could produce fractures. The Iowa group found 3 kg to be the average lateral condensation pressure exerted by six endodontists. Although they found the incidence of immediate vertical root fractures to be low at 3 kg, they speculated that a buildup of root distortion, “stored” in the root, could well be released later as a fracture. They produced more frac-
tures with the D-11 hand spreader than with the less tapered B-finger spreader.333

At Melbourne University researchers compared load and strain using hand versus finger spreaders and found “that strains generated by finger spreaders were significantly lower than hand spreaders.” They also concurred with the Iowa group when they noted that lateral condensation may lead to incomplete root fractures and that these fractures may later lead to full vertical fractures under the stresses of restoration or mastication.334 Blum described the intracanal pressure developed during condensation as the “wedging effect” and measurements graphed from a force analyzer device showed that gutta-percha deformation occurs at only 0.8 kg for lateral condensation.335

Researchers at the University of Washington found it took 7.2 kg (15.8 lbs) to fracture a maxillary central incisor. However, 16% of their maxillary anterior teeth fractured at loads under 10 kg. They felt that 5 kg (11 lbs) were a “safe load” for these husky teeth.336 When this same group tested mandibular incisors, they produced fractures with only 1.5 kg (3.3 lbs) of load, and 22% of their lower incisors fractured at loads less than 5 kg, in marked contrast to the maxillary incisors and canines. In the lower incisor sample, fractures occurred when only three accessory points were compacted. Like the Iowa and Melbourne groups, they speculated that “vertical root fractures might not be detected clinically until long after the fracture was initiated.”337 Again at Iowa, the relationship between tooth reduction and vertical fracture was studied to show that vertical root fracture did not occur in maxillary anterior teeth under a constant force of 3.3 kg for 15 seconds until 40% of the total canal width was reduced and was always preceded by visible craze lines.338

From Greece, Morfis condemned lateral condensation and long post placement as responsible for root fractures. He reported 17 (3.69%) vertical fractures of 480 endodontically treated teeth.339

Using engineering models, a US Air Force group found that “lateral condensation required a smaller amount of force than vertical condensation to produce the same amount of stress near the apex…” whereas “the average stress throughout the entire canal was higher for vertical condensation….” They felt that the
term lateral condensation may be somewhat of a misnomer,” and that “lateral condensation may be more likely to produce undesirable stress concentrations than is vertical condensation.”340 This was noted earlier at the University of Georgia, when it was stated that “the force of the spreader is apparently transmitted 1 to 2 mm beyond the spreader tip and molds the points and sealer against the walls as it forces them apically.”315 Essentially the same thing was noted at the University of North Carolina.341

Nickel-Titanium Spreaders
Studying the distribution of forces in lateral condensation, a US Army group used photoelastic models to demonstrate that nickel-titanium spreaders induced stress patterns distributed along the surface of curved canals compared to concentrated spikes of stress when stainless steel spreaders were used.342 They also pointed out that, because of their flexibility, nickel-titanium “spreaders penetrated to a significantly greater depth than the stainless steel spreaders in curved canals.”343

Variations of Lateral Compaction. The preceding illustration of obturating a straight canal by lateral compaction applies with modifications for filling curved canals, immature open apices, or tubular canals.

Curved Canals. Virtually all canals exhibit some curvature. Over 40% of maxillary lateral incisors have a “breaking curve” in the apical third. Over 50% of the palatal roots of maxillary first molars curve back to the buccal. These are examples of the apical curves. General root curvature is apparent radiographically in most of the posterior teeth. Many “hidden” curves to the buccal or lingual cannot be seen radiographically in anterior teeth.

Lateral compaction of curved canals can be very effective in most cases. However, it may be difficult if not impossible in severely curved, dilacerated, or bayonet canals. If smaller, more flexible spreaders cannot reach within the apical 1 mm, or the taper of the preparation is less than that of the spreader, then lateral condensation is not the technique of choice. Teasing a flexible primary point smaller than size 30 to place at the apex, or expecting a stiff spreader to reach within 1 mm of the working length precludes the use of proper lateral compaction. There are other techniques that use warmed or thermoplasticized gutta-percha that are more applicable. They will be discussed subsequently.

In the vast majority of curved canals, where lateral compaction is applicable, the routine is exactly the same: sealer placement and primary point placement, followed by spreaders and auxiliary points. Alternating spreader sizes is usually required to reach the premeasured depth in narrowly prepared canals. One must know, however, that more vertical force will be exerted against the primary point as the spreader will tend to catch in the gutta-percha and force it apically (Figure 11-45). Overfills occur with greater frequency when the vertical force is greater. This also occurs when the spreader taper is greater than the canal preparation. Nickel-titanium spreaders will penetrate to greater depths and distribute forces more evenly than will stainless steel spreaders in curved canals (Figure 11-46).

Immature Canals and Apices. The immature canal is complicated by a gaping foramen. The apical opening is either a nonconstrictive terminus of a tubular canal or a flaring foramen of a “blunderbuss” shape. Every effort should be made to attain the genetically programmed closure of the foramen that remains open because of early pulp death. This can be accomplished by apexification, a method of recharging the growth potential and restoring root growth and foramen closure. Apexification is discussed thoroughly in chapter 15.

If apexification fails or is inappropriate, special methods must be used to obturate the canals without benefit of the constrictive foramen serving as a confining matrix against which to condense. Fortunately, in...
most of these cases, pulps of straight-root maxillary incisors have been devitalized by impact trauma. In other cases, the foramen has been either trephined to allow for abscess drainage or destroyed by the erosion of external root resorption. Occasionally an immature first molar with pulp necrosis from early caries is a candidate. In either case, calcium hydroxide apexification should be first tried.

Complete obturation requires the use of the largest gutta-percha points customized ("tailor made") to fit the irregular apical stop or barrier. Lateral compaction is not the technique of choice because the resistance of the canal walls for lateral pressure is reduced in immature teeth and the greater bulk of gutta-percha requires an even greater force to deform. Remember that compaction occurs from the canal wall into the mass of gutta-percha. Gutta-percha, in seldom-used sizes, can become brittle in storage and requires even greater pressure to deform. Warm gutta-percha techniques are best suited for filling immature canals and apices.

Tubular Canals. The large tubular canal with little constriction at the foramen may best be filled with a "coarse" primary gutta-percha cone that has been blunted by cutting off the tip. Sometimes the canal is such that a large "tailor-made" point must be used. In either case, the "trial point" should pass the tests of proper fit.

The objective of the primary point is to block the foramen, insofar as possible, while auxiliary points are condensed to complete the filling (Figure 11-47). The length of tooth must be marked on the spreader so that it will not be forced out the apex. With care, a well-compacted filling may be placed without gross overfilling of either cement or gutta-percha. Warm gutta-percha techniques should be considered in larger canals after the apical seal has been achieved by customizing or lateral compaction.

Tailor-Made Gutta-Percha Roll. If the tubular canal is so large that the largest gutta-percha point is still loose in the canal, a tailor-made point must be used as a primary point. This point may be prepared by heating a number of large gutta-percha cones and combining them, butt to tip, until a roll has been developed much the size and shape of the canal (Figure 11-48).
The roll must be chilled with a spray of ethyl chloride or ice water to stiffen the gutta-percha before it is fitted in the canal. If it goes to full depth easily but is too loose, more gutta-percha must be added. If it is only slightly too large, the outside of the gutta-percha can be flash-heated over the flame and the roll forced to proper position. By this method, an impression of the canal is secured (Figure 11-49).

The outer surface of the stiffened point may also be softened by heat or “flash”-dipping the point in chloroform, eucalyptol, or halothane (Figure 11-50, A). By repeating this exercise, one can essentially take an

Figure 11-48 Preparation of “tailor-made” gutta-percha roll. A, Number of heated, coarse, gutta-percha points are arranged butt to tip, butt to tip on sterile glass slab. B, Points are rolled with spatula into rod-shaped mass. C, By repeated heating and rolling, the roll of gutta-percha is formed to approximate size of canal to be filled. No voids should exist in mass. D, Before trial point testing of tailor-made roll, gutta-percha should be chilled with ethyl chloride spray.

Figure 11-49 Trial point radiograph of tailor-made gutta-percha point. Space exists alongside this roll, which indicates it should be enlarged and retested.

Figure 11-50 Chloroform dip technique. A, Note that just the tip is immersed and for only 1 second. B, Final compaction of tubular canal. Warm gutta-percha/vertical compaction is preferred technique for cases with such thin walls. (Courtesy of Dr. Carl W. Newton.)
internal impression of the canal. A mark is made on the buccal surface of the cone and it is dipped in alcohol to stop the action of this solvent. Alcohol can also be used to assist in drying the canal prior to filling. Some shrinkage may alter the final impression and any compaction before the solvent has evaporated will permit the point to continue to flow under pressure.

Simpson and Natkin have suggested a specialized filling technique for those teeth with tubular canals but closed apices. These are the roots that were originally blunderbuss in shape but have been induced to complete their growth by the introduction into the root canal of a biologically active chemical, such as calcium hydroxide.

**Efficacy of Lateral Compaction.** As previously stated, lateral compaction of gutta-percha with sealer is the obturation technique against which other techniques are measured. In some cases, it has been proved better than other methods. In other reports, it was found to be as effective as other techniques. But in other citings, it proved not as adequate.

Weine, a longtime advocate of lateral compaction, and his associates have shown that lateral compaction, done correctly, provides an optimum obturation of the entire canal. The Loyola research was prompted by Schilder’s characterization of lateral compaction as ineffective, that “…gutta-percha cones never merge into a homogeneous mass, but they slip and glide and are frozen in a sea of cement” (Figure 11-51).

The Weine group enlarged curved canals in plastic blocks to size 30 apically and flared to size 45 coronally. They then cemented into place a pink No. 30 gutta-percha point and followed it with a No. A finger plugger (with a rounded tip) used as a spreader. Each No. 20 auxiliary gutta-percha point that followed was specially colored a different color.

As Figure 11-52 shows, the primary and accessory points more than adequately fill the canal and illustrate how the spreader uses the wall opposite to provide the compressive force of the gutta-percha against the opposite canal wall. And far from “being frozen in a sea of cement,” the points dominate the space with only two small flashes of cement showing.

The Indiana research group also showed the efficacy of lateral compaction as well as the paramount importance of thoroughly débriding the canal. Fifteen days following obturation, they found healing already under way. After 45 days, only slight inflammation remained. At the end of 1 year, even though one canal was overfilled (Figure 11-53, A), the tissue was remarkably healthy. In marked contrast, a poorly filled canal exhibited chronic apical periodontitis at 75 days (Figure 11-53, B). All of the unfilled control teeth suffered severe periradicular lesions.

One must conclude that the objectives of root canal therapy are well met by total canal débridement and obturation by lateral compaction. Failures will be due to neglect of these objectives plus overzealous compaction leading to fracture.

**Chemically Plasticized Cold Gutta-percha.** A modification of the lateral compaction technique involves
Figure 11-52  Cross-sections of an in vitro study, demonstrating the efficacy of lateral compaction of cold gutta-percha points, each point a different color. A, Single primary point 1.0 mm from apex apparently fills canal. B, First auxiliary point added following distortion of master point, 2.0 mm from apex. C, Second and third auxiliary points 3.0 mm from apex. Canal still totally obturated. D, Second, third, and fourth points fill canal. Primary point not visible. Small amount of sealer at 4 o’clock and 7 o’clock positions 4.0 mm from apex. E, Fifth point joins other; master point does not show. Small amount of sealer at 5 o’clock and 7 o’clock 5.0 mm from apex. F, Sixth point added; master point “reappears” 6.0 mm from apex. G, Seventh point in place, no sealer apparent, canal totally obturated, 7.0 mm from apex. Reproduced with permission from Sakhal S et al.382
the use of a solvent to soften the primary gutta-percha point in an effort to ensure that it will better conform to the aberrations in apical canal anatomy. This is a variation of a very old obturation method, the so-called Callahan-Johnston technique first promulgated by Callahan in July of 1911. The problem with the original technique centered around the use of too much of the chloroform solvent. Price, a foe of Callahan, set out to prove how ineffective the Callahan root fillings were. Although Callahan claimed that the mixture of chloroform, rosin, and gutta-percha did not shrink, Price observed a 24% decrease in volume in vitro. The chloroform had evaporated leaving powdered gutta-percha.

Today’s use of solvents is quite modest in comparison with the older methods. Usually only the tip of the point is dipped in the solvent and then only for 1 second (see Figure 11-50, A). Two or three dips will cause serious leakage.

In this technique the primary point is blunted and fitted 2.0 mm short of the working length. It is then dipped in the solvent for 1 second and set aside while sealer is placed in the canal. This allows the solvent to partially evaporate. Too much solvent, as with a two- or three-dip method, will materially increase leakage. Not only does the gutta-percha volume shrink as the solvent evaporates in the canal, the sealer leaks as well, probably because of solvent dissolution.

To begin the obturation by lateral compaction, one must immediately position the customized master point to its full measured length and then spread it aside to allow the softened gutta-percha to flow. The spreader is rotated out and is followed by additional points, spreader and points. Because 2.0 mm of the master tip have been solvent softened, it will flow to place to produce “smooth, homogeneous, well-condensed gutta-percha fills closely adapted to the internal canal configuration in the apical third, including the filling of lateral canals, fins, and irregularities.” An Israeli group warns, however, that the point should be positioned and spread within 15 seconds of being softened; otherwise, it will have lost its plasticity. After 30 seconds of air drying, it changes shape.

The principal solvent used in this technique is chloroform. At one time there was concern that it was carcinogenic, but it has recently been cleared for clinical use in dentistry by the FDA, Occupational Safety and Health Administration, and ADA. In any event, other solvents such as eucalyptol, halothane, xylene, and rectified turpentine have been evaluated as substitutes for chloroform.

In addition to the popular dip technique, sealers are prepared by dissolving gutta-percha in these solvents as well as in rosin and balsam. These mixtures have long been popular as sealers and dips for gutta-percha points. Such mixtures are called chloropercha, Kloropercha, or...
Sealers such as CRCS (Calciobiotic Root Canal Sealer) and Wach’s Sealer, respectively, contain the solvents oil of eucalyptol and Canada balsam. Efficacy of Solvent-Customized Gutta-percha Master Points. As the University of Washington group noted, customizing master points with solvents improves the seal of gutta-percha. At the University of Iowa, researchers found essentially the same thing. Peters found virtually no solubility in distilled water after 2 years when the chloroform dip method was used with lateral compaction.389a Goldman found Kloropercha as a sealer superior to chloropercha or lateral compaction with ZOE sealer.390 Kloropercha contains balsam, rosin, and zinc oxide in addition to gutta-percha and chloroform, which makes it more homogeneous. The US Army Research Institute also tested chloropercha and Kloropercha. Initially, with the solvent/gutta-percha filling, they achieved dramatic results (Figure 11-54, A). After 2 weeks, however, chloropercha shrank 12.42% and the Kloropercha 4.68%, whereas the simple chloroform dip shrank only 1.4%. The comparative results versus lateral and vertical compaction were dramatic (Figure 11-54, B and C).

Morse and Wilcko recommend eucalyptol as a solvent to form eucapercha. It shrinks 10% less than chloropercha.392,393 Others found the quick-dip technique superior to eucapercha as a sealer.394 Halothane and eucalyptol, as alternatives to chloroform, were found to be no better in dissolving or sealing ability. However, Morse and the Temple University group used eucapercha as a sealer and noted that it shrinks less than warm gutta-percha or gutta-percha/chloropercha.398 A Tel Aviv group summarized best the value of customized master points softened by solvents. They found that chloroform-dipped points provided a significantly better seal than standardized points when obturating “flat” canals. Few canals are perfectly round in shape.

Vertical Compaction of Warm Gutta-percha*

Over 30 years ago, Schilder introduced a concept of cleaning and shaping root canals in a conical shape and then obturating the space “three-dimensionally” with gutta-percha, warmed in the canal and compacted vertically with pluggers. It was his contention that all the “portals of exit” were clinically significant and would be obturated with a maximum amount of gutta-percha and a minimum amount of sealer (Figure 11-55).

Figure 11-54 Compaction results from three methods of obturation purposely done without sealer. A, Chloropercha filling presents best immediate appearance. Unfortunately, a 12.4% shrinkage follows, leading to massive leakage. B, Lateral compaction—cold gutta-percha showing coalescence of primary and accessory points at apex but separating midcanal. C, Warm gutta-percha/vertical compaction. Filling is homogeneous; replication is excellent. Reproduced with permission from Wong M et al.409

*A John West gratefully acknowledges the assistance of Herbert Schilder and James Clark in preparing this section.
Fitting the Master Gutta-percha Cone. Following the preparation of a thoroughly cleansed and continuously tapering canal, the critical step of fitting the master cone is the next important feature of this technique. For this, the conventional cone-shaped gutta-percha points are used, not the standardized numbered points. The cone-shaped gutta-percha more closely mirrors the tapered canal shape (Figure 11-56). The primary cone is virtually tailor fit, particularly in the apical third (Figure 11-57).

The cone is placed to reach the radiographic terminus and then cut back slightly short (0.5–1.0 mm) of this length (see Figure 11-57). This allows heat molding of the round cone into the nonround portal of exit and minimizes sealer/tissue contact (Figure 11-58). Under cone-fit guidelines, the shorter, wider, and straighter the canal, the farther the cone should be cut back from the radiographic terminus. Conversely, the longer, more curved, and narrower the canal, the closer the cone should fit to the radiographic terminus. Beginners often cut back the cone too much.

Occasionally the cone fit does not reach the apex. In this event, one should attempt a smaller cone or, better yet, improve the shape of the canal. In short, fit the cone 0.5 to 1 mm short of the radiographic terminus and it should possess good tugback.

As stated earlier, fit of the master cone is the key to success in this technique—a successful relationship between the radicular preparation and the master cone. Cleaning and shaping and obturation are clinically inseparable. When the gutta-percha is subsequently warmed and compacted, it fills not only the critical parts of the canal but the cleaned portals of exit as well (see Figure 11-57, C). When compacted, the primary cone provides the body of the warm “wave of compaction” moving apically and then a warm wave of compaction moving coronally. The cone must fit tightly in the apical third, that is, have “tugback,” and have diminished taper toward the middle and coronal thirds as well.

It is typical of vertical compaction that more than one portal of exit per canal will be filled—two portals of exit per canal in one sampling. In the graduate endodontic clinic at Boston University, more than one foramen is filled over 40% of the time. Similar results are reported at the University of Washington (Figure 11-59). There is virtually no risk of compacting too short or too long if the first cone fits properly.

Prefitting the Vertical Pluggers. Practitioners of warm gutta-percha vertical compaction prefer using a set of pluggers designed by Schilder (Dentsply/Maillefer; Tulsa, Okla.), a wider plugger for the coronal third of the canal, a narrower plugger for the middle third, and the narrowest plugger for the apical third of the canal. The objective is for the widest appropriate...
plugger to capture the maximum cushion of warm gutta-percha as the heat wave is carried apically. Only one or two pluggers may be needed for shorter teeth, whereas three or four are used in longer canals. Most cases require three graduated sizes.

Schilder pluggers are marked with serrations every 5 mm, so that the depth that each instrument penetrates should be recorded by plugger number and depth of penetration. The pluggers are then set aside for immediate use.

Heat Transfer Instrument. Initially, an instrument designed much like a spreader was used to transfer heat from a Bunsen burner to the gutta-percha. It was heated “cherry-red,” immediately carried into the canal, sub-

Figure 11-57  Fitting the master gutta-percha cone. A, Cone fit to radiographic terminus. B, Cone is cut back 0.5 mm. When placed to depth, the incisal reference remains the same. C, Compaction film reveals two apical foramina as well as large lateral canal opposite lateral lesion. (Courtesy of Dr. John D. West.)

Figure 11-58  Warm gutta-percha conforming to “egg-shaped” canal. A, Primary gutta-percha cone fits 0.5 to 1.0 mm short of radiographic apex. B, Cold plugger advances the thermoplasticized gutta-percha into apical constrictures. C, Vertical pressure compacts warmed gutta-percha into nonround foramen. (Courtesy of Dr. John D. West.)
merged into the mass of gutta-percha, and drawn through the gutta-percha for 2 or 3 seconds to allow the heat to transfer from the heat carrier. It was then withdrawn in a slightly circular wiping motion, “freezing” some of the gutta-percha onto the heat carrier. Successive waves of vertical compaction immediately followed.

The Schilder heat carrier has been essentially superseded by the Touch 'n Heat 5004 (SybronEndo/Analytic; Irvine, Calif.), an electronic device specially developed for the warm gutta-percha technique (Figure 11-60). It exhibits the same thermal profile as the original heat carrier but has the advantage of generating heat automatically at the tip of the instrument. Battery or AC models are available.

Root Canal Sealer. Practitioners of this technique generally prefer using Kerr Pulp Canal Sealer, Richert's original ZOE cement that contains rosin as well as precipitated silver used as a radiopaquing medium. The advantages, they feel, are the short setting time and low resorbability.406 Recently, Kerr introduced Pulp Canal Sealer EWT, which allows for Extended Working Time.

Step-by-Step Procedure of Vertical Compaction of Warm Gutta-percha

1. Dry the canal! This is best achieved by using 100% alcohol irrigated deep within the root canal system using thin, safe-tipped irrigating “needles.” The canal is then dried with paper points and air dried with the Stropko irrigator (SybronEndo/Analytic Tech; Irvine, Calif.). Confirm the patency of the foramen with an instrument smaller than the last size instrument used to develop the apical preparation.

2. Fit the appropriate gutta-percha cone to the patent radiographic terminus. It should visually go to full working length and exhibit tug-back. Confirm the position radiographically. Cut off the butt end of the cone at the incisal or occlusal reference point (Figure 11-61, A).

3. Remove the cone and cut back 0.5 to 1.0 mm of the tip, reinsert, and check the length and tug-back. The cone’s apical diameter should be the same diameter as the last apical instrument to reach the radiographic terminus of the preparation (Figure 11-61, B). Remove the cone, dip it in alcohol, and curve it slightly by drawing it through a folded 2 × 2 gauze so that it will more easily follow the probable curved shape of the canal. Set the cone aside.

4. Prefit the three pluggers to the canal preparation: first the widest plunger to a 10 mm depth (Figure 11-61, C); next, the middle plunger to a 15 mm depth (Figure 11-61, D); finally, the narrowest plunger to within 3 to 4 mm of the terminus (Figure 11-61, E). Record the lengths of the desired plunger depth.

5. Deposit a small amount of root canal sealer in the canal with a Handy Lentulo spiral. (Dentsply/Maillefer; Tulsa, Okla.). Lightly coat all of the walls.

6. Coat the apical third of the gutta-percha cone with a thin film of sealer.

7. Grasp the butt-end of the cone with cotton pliers and slide the cone approximately halfway down the canal. Then gently follow it fully into place with the closed tip of the cotton pliers (Figure 11-61, F). In a curved canal, the cone will rotate as it responds to the curvature.

8. Using the Touch 'n Heat 5004 heat carrier, sear off the cone surplus in the pulp chamber down to the cervical level (Figure 11-61, G). This transfers heat to the coronal third of the gutta-percha cone.
and creates a platform to begin the first wave of compaction.

9. Using the widest vertical plugger that has previously been coated with cement powder as a separating medium, the gutta-percha is folded into a mass and compacted in an apical direction with sustained 5- to 10-second pressure (Figure 11-61, H). This is the first heat wave. The temperature of the gutta-percha has been raised 5 to 8°C above body temperature, which allows deformation from compaction. At this temperature (42 to 45°C), the gutta-percha retains its same crystalline beta form with minimal shrinkage as it cools back to body temperature.

10. The second heat wave begins by introducing the heat carrier back into the gutta-percha, where it remains for 2 to 3 seconds (Figure 11-61, I) and, when retrieved, carries with it the first selective gutta-percha removal (Figure 11-61, J).

11. Immediately, the midsized coated plugger is submerged into the warm gutta-percha. The vertical pressure also exerts lateral pressure. This filling mass is shepherded apically in 3 to 4 mm waves created by repeated heat and compaction cycles (Figure 11-61, K).

12. The second heating of the heat carrier warms the next 3 to 4 mm of gutta-percha and again an amount is removed on the end of the heat carrier (Figure 11-61, L).

13. The narrowest plugger is immediately inserted in the canal and the surplus material along the walls is folded centrally into the apical mass so that the heat wave begins from a flat plateau. The warmed gutta-percha is then compacted vertically, and the material flows into and seals the apical portals of exit (Figure 11-61, M).

14. The apical “down-pack” is now completed, and if a post is to be placed at this depth, no more gutta-percha need be used (Figure 11-61, N).

15. “Backpacking” the remainder of the canal completes the obturation. The classic method of backpacking consists of placing 5 mm precut segments of gutta-percha in the canal, cold welding them with the appropriate plugger to the apical material (Figure 11-61, O), warming them with the heat-carrier (Figure 11-61, P), and then compacting. It should be noted that no selective removal of gutta-percha is attempted in the backpacking (Figure 11-61, Q). This sectional procedure is continued with heat and the next wider plugger until the entire canal is obturated (Figure 11-61, R).

16. An alternative method of backpacking may be done by injecting plasticized gutta-percha from one of the syringes, such as Obtura II (Obtura/Spartan, USA). In any event, the plasticized gutta-percha must be compacted with vertical pluggers to ensure its flow against canal walls, to weld it to the apical materials, and to minimize shrinkage (Figure 11-61, S).

17. The final act involves the thorough cleansing of the pulp chamber below the CE junction, the addition of an appropriate barrier, and the placement of a permanent restoration (Figure 11-61, T). In molar teeth, extra sealer should be placed in the chamber area, warm gutta-percha is syringed into the chamber flow, and the gutta-percha is compacted with large amalgam pluggers to ensure that any furcal portals of exit will be filled prior to final restoration (Figure 11-62).

Like all dental techniques, vertical compaction of warm gutta-percha is technique sensitive. It is imperative, therefore, to seek professional training in this special obturation method.407

Efficacy of Vertical Compaction of Warm Gutta-percha. Warm gutta-percha, vertically compacted, has proved most effective in filling the canals of severely curved roots and roots with accessory, auxiliary, or lateral canals, or with multiple foramina. Since the first indication of such anatomic variations may be observed during the filling procedure, it behooves the dentist to use a filling technique that ensures obturation in case such unusual canals are open and patent.

The chief proponents of the warm gutta-percha technique at Boston University point out that consistent success in obturation will be achieved only when the canal is properly cleaned and shaped, and when copious amounts of sodium hypochlorite are used to flush away the debris, bacteria, and dentinal filings.408 After this proper preparation, predictable three-dimensional obturation with vertical compaction is easily accomplished. In this technique, the two concepts, cleaning and shaping and three-dimensional obturation, are inseparable.

As previously stated, very few microleakage studies have been done comparing warm gutta-percha/vertical compaction with other techniques. Lateral compaction is usually used as a control in these studies. The few that do exist, however, speak favorably for warm/vertical compaction.

Brothman compared lateral and vertical techniques and found “no statistically significant difference in filling efficiency.”356 He reported, however, a significantly greater incidence of accessory canal filling with sealer by vertical compaction. He concluded that ribbon-shaped canals were better filled by lateral compaction, whereas “for cen-
Electric canals, vertical condensation appears better. Reader and Himel reported “significantly more gutta-percha in the lateral canals” when compared with cold lateral or warm lateral/vertical compaction. Torabinejad et al. compared a number of obturation techniques and concluded that comparable results were achieved with all four methods, but reported close adaptation in the middle and apical thirds by the vertical method. Wong et al. reported a homogeneous filling with excellent replication. At Dalhousie University, three obturation methods were compared and all three “techniques proved equally satisfactory,” although the researchers did note “cold-welds” with vertical compaction. Lugasse and Yee also noted the cold welds as well as “microscopic voids, folds and inclusions scattered randomly throughout the root canal.” A US Army group tested three different methods and found the differences in radioactive microleakage to 45Ca were not significant.

A tendency to overfill the canal while using the warm gutta-percha/vertical compaction technique was noted by a Lebanese group who reported that “apical cone displacement was greater with vertical compaction.” Clinically, they observed that “overextension is more likely to occur…when the master cone is adapted only 0.5 mm short.” There were no overextensions with lateral compaction.

Schilder has twice reported to meetings of the American Association of Endodontists his evaluations.
of success and failure when his recommendations of cleaning and shaping and obturation with warm gutta-percha and vertical compaction were followed. The cases were done by endodontic graduate students at Boston University.

The first was a radiographic study, treatment of 100 maxillary anterior teeth with periradicular lesions. The lesions ranged in size from 8 to 35 mm. The age range was 14 to 84 years and involved both sexes. Radiographic observations were made at 6, 12, 18, and 24 months. Healing was judged as totally healed (90%), partially healed (75%), no healing (50%), or worse. Total healing or 90% healing was noted in 56% of the cases within the first 6 months. At 24 months, 99% of the 100 cases “were fully healed.” The one failed case (an 84-year-old woman) was subsequently revealed by surgery to have an apical bifurcation. Apicoectomy below the bifurcation allowed normal healing within 1 year.

On the basis of this radiographic study of maxillary anterior teeth, Schilder reported 100% success after 2 years for cleaning and shaping and three-dimensional obturation by warm gutta-percha/vertical compaction.
obturation, new bone formation was noted

Furcal accessory canal and lateral canal, mesial root

Endodontics

Figure 11-62  Furcal accessory canal and lateral canal, mesial root filled by vertical compaction of warm gutta-percha. (Courtesy of Dr. John D. West.)

As a follow-up to the preceding report, Schilder presented in 1977 a histologic study of 25 lesions of endodontic origin. Schilder replied that the cracks seen in the Temple University microphotographs were laboratory artifacts (H. Schilder, personal communication, August 1977). More recently, a US Army study done with mathematical models and “finite element analysis” suggested “that lateral condensation may be more likely to produce undesirable stress concentrations than is vertical condensation.” These researchers also said that the term “lateral condensation may be somewhat of a misnomer,” that it produced more stress with less force near the apex (where a root is finer and more likely to fracture) than did vertical compaction. However, “the average stress throughout the entire canal was higher for vertical condensation...”324 A group at the University of Iowa tested both lateral and vertical compaction techniques for stresses induced and concluded that “the highest stress concentrations occurred in the apical third of the root...and progressed incisally.” Both lateral and vertical stresses were culpable.340

Another concern relates to the temperatures generated within the canal from the warming process. The Boston University group found the maximum temperature in the body of the canal to be 80°C (176°F), whereas in the apical region the temperature peaked at 45°C (113°F).415 A US army group reported that “the use of hot instruments for the condensation of filling material did not appear to endanger the integrity of the lateral periodontium.”416 In later research, an Army group again studied intracanal temperatures, produced this time with the Touch ‘n Heat unit. They felt the operator should restrict the use of the unit to lower power settings of #2 or #3 and increase the length of time the heated tip is activated. They warned that at the top setting of #6 the unit could increase the intracanal temperature to as high as 114.51°C, a potentially damaging temperature.417 Lee et al., at the University of Illinois, remarked that “the critical level of root surface heat required to produce irreversible bone damage is believed to be >10° C.” In this context, they noted that “caution should be used with the Touch ‘n Heat and flame heated carriers on mandibular incisors.”418

System B: Continuous Wave of Obturation

Buchanan, long an impressive advocate of the warm gutta-percha vertical compaction technique, has developed a variation of the method that he perceives as faster and more accurate. Concerned with the complexity and time consumed in completing an obturation, he retained the principles of vertical compaction but improved the methodology. Working with Analytic Technology, which had developed the Touch ‘n Heat
device for warming gutta-percha in the canal, Buchanan and Analytic perfected the System-B Heat Source and associated pluggers (SybronEndo/Analytic; Irvine, Calif.). This new heat source monitors the temperature at the tip of the heat-carrier pluggers, thus “delivering a precise amount of heat for an indefinite time.”

System B obturation is predicated on a precise preparation, perfectly tapered to match as closely as possible the shape of the nonstandardized gutta-percha cones—fine, fine-medium, medium, and medium-large (F, FM, M, and ML). Another Buchanan/Analytic development is gutta-percha cones that match the shape produced during canal preparation using Greater Taper instruments.

Downpack Technique. An appropriate size gutta-percha cone, matching the completed preparation shape, is tested in the canal to be sure it goes fully to place. This is confirmed radiographically. “Continuous Wave Technique requires good canal shape and meticulous gutta-percha cone fitting. The cone must fit in its last 1 mm, and fit to full length before minimal cutback (less than 0.5 mm).” The cone is then removed and the corresponding plugger is tried for size in the canal. It should stop at its “binding point,” about 5 to 7 mm short of the working length. The stop attachment is then adjusted at the coronal reference point and the plugger is removed and attached to the Heat Source. The canal is dried.

The primary point is coated with sealer and pushed into place, all the way to the apical stop. The Heat Source is activated, set for “use” and “touch,” and the temperature is set for 200°C and the power dial at 10. The cone is then seared at the orifice with the preheated plugger tip, and the preheated plugger is then “driven” smoothly through the gutta-percha to within 3 to 4 mm of its binding point in the canal. This will take about 2 seconds. Maintaining apical pressure, the plugger will continue to move apically, and at this time the heat switch is released. The plugger is held there, cold, under sustained pressure, for an additional 10 seconds. It is during this period the gutta-percha flows to the apical matrix and into accessory canals. The pressure also compensates for the shrinkage that might occur as the mass cools.

To remove the plugger: while still maintaining apical pressure, the heat switch is activated for only 1 second followed by a 1-second pause. The “cold” plugger is then quickly withdrawn. Following radiographic confirmation, the remainder of the canal is now ready for backfill.

Backfill Technique. Using the same size gutta-percha cone and plugger, the cone is coated with sealer and positioned in the backfill space in the canal. The System B temperature is now set at 100°C. Preheat the plugger out of the canal for only ¼ second, cut the heat, but immediately plunge the plugger into the backfill cone and hold it in place for 3 to 5 seconds as the gutta-percha cools. Another cone is added in the backfill space and heat is again applied. The final plugging is done with a large cold regular plugger. Another method of backfilling is to use the Obtura II gutta-percha gun.

To date there have been few reports on the success of the System B Technique. On the other hand, concern has been expressed about the 200°C heated plugger so near the thin root at the apex. The short period of time this high heat is delivered, however, seems to preclude any periodontal damage.

Warm/Sectional Gutta-percha Obturation. The use of small warmed pieces of gutta-percha, the so-called sectional obturation technique, is one of the earliest modifications of the vertical compaction method described earlier. Webster might well have been describing this procedure in 1911 when he spoke about filling “with gutta-percha, using points heated and well packed in with hot instruments.” Eventually this became known as the “Chicago” technique since it was widely promoted by Coolidge, Blayney, and Lundquist, all of Chicago. It was also the favorite technique of Berg of Boston.

The method begins like other methods: fitting the plugger to the prepared tapered canal (Figure 11-63, A). It should fit loosely and extend to within 3 mm of the working length. A silicone stop is then set on the shaft marking this length (Figure 11-63, B). Next, the primary gutta-percha point is blunted and carried to place. It should be fitted 1 mm short of the working length and confirmed radiographically (Figure 11-63, C). Upon removal, 3 mm of the tip of the point are cleanly excised with a scalpel (Figure 11-63, D) and this small piece is then luted to the end of the warmed plugger (Figure 11-63, E). Sealer is placed, lining the canal, the gutta-percha tip is warmed by passing it through an alcohol flame, and it is then carried to place. Under apical pressure, the plugger is rotated to separate the gutta-percha (Figure 11-63, F) and it is thoroughly packed in place. At this point, it is best to expose a radiograph to be sure the initial piece is in position (Figure 11-63, G). If so, the remainder of the canal is filled in a like manner, compacting additional pieces of warmed gutta-percha until the canal is filled to the coronal orifice (Figure 11-63, H).

If a post is planned, the compaction can stop after the second piece, leaving 5 to 6 mm of apical canal filled. Another variation of heat-softening the gutta-percha is
to soften each piece in chloroform or halothane in a quick “dip.”

Rather than laboriously adding sections of gutta-percha, backfilling may be done with thermostaticized gutta-percha from one of the gutta-percha “guns.” In evaluating such backfill, Johnson and Bond noted that “it may be clinically acceptable to backfill canals up to 10 mm in a single increment using sealer and the Obtura II gutta-percha system.”

**Lateral/Vertical Compaction of Warm Gutta-percha.** Considering the ease and speed of lateral compaction as well as the superior density gained by vertical compaction of warm gutta-percha, Martin developed a device that appears to achieve the best qualities of both techniques. Called Endotec II (Medidenta Inc; Woodside, N.Y.), the newly designed device is a battery-powered, heat-controlled spreader/plugger that ensures complete thermo-softening of any type of gutta-percha. It is supplied with two AA batteries that provide the energy to heat the attached spreader/plugger tips (Figure 11-64). The quick-change, heated tips are sized equivalent to a No. 30 instrument, are autoclavable, and may be adjusted to any access angulation. Martin claims that the “Endotec combines the best of the two most popular obturation techniques: warm/vertical and the relative simplicity of lateral compaction” (H. Martin, personal communication, December 1999).

Canal cleaning and shaping for this technique is a continuous taper design with a definite apical stop. After the primary point is fitted to full working length, the hand spreader and the Endotec plugger/spreader are fitted as well. At this point, silicone stops are placed to mark the length of canal.

After drying of the canal, a limited amount of sealer is applied. The primary point is then firmly positioned and gently adapted with a hand or finger spreader. It has also been recommended that one or two additional gutta-percha points be placed to reduce the possibility that the warm plugger will loosen the point when the tip is retracted.
At this juncture the Endotec plugger is placed in the canal to full depth. The activator button is pressed and the heating plugger is moved in a clockwise motion. The heat button is then released and the plugger cools immediately. It is now removed from the gutta-percha with a counterclockwise motion. This lateral compaction has formed a space for an additional point to be added, after which the plugger is again placed, heated, moved clockwise for 10 to 15 seconds, cooled, and retracted counterclockwise (Figure 11-65). Now the plugger can be used cold to compact the softened gutta-percha, followed again by warming and lateral space preparation for additional points.

In this manner (lateral compaction with the heated plugger to provide space for additional gutta-percha, and the vertical compaction with the cooled plugger to condense the heat-softened gutta-percha) the canal is entirely obturated. Finally, a cold hand plugger can be used to firmly condense the fused gutta-percha bolus.

The Endotec can also be used to soften and remove gutta-percha for post preparation or in the event of retreatment. An Air Force group also found they could measurably improve compaction while obturating a mandibular molar with a C-shaped canal by using the EndoTec in what they termed a “zap and tap” maneuver: preheating the Endotec plugger for 4 to 5 seconds before insertion (zap) and then moving the hot instrument in and out in short continuous strokes (taps) 10 to 15 times. The plugger was removed while still hot, followed by a “cold spreader with insertion of additional accessory points.”

Concern has been voiced that heat from the tip will damage the periodontium, and that the lateral/vertical pressure exerted will be too stressful. In the first instance, it was found there was “no heat related damage to periodontal tissues from either of the two methods employed”: Endotec and warm/vertical compaction. A US Army group also tested for heat damage from the Touch ‘n Heat unit, which produces more heat (816°C) than the Endotec. They pointed out that even though the internal gutta-percha mass reached 102°C, gutta-percha and dentin are poor heat conductors, and this temperature “would not be of sufficient magnitude to cause damage in the periodontal tissues.”

In the second instance, that of stress development, Martin and Fischer have shown, in a photoelastic stress test, that “warm lateral condensation (Endotec) created less stress during obturation than did cold lateral condensation.”

**Efficacy of the Warm/Lateral Technique.** Because gutta-percha is heated with this technique, there must be a commensurate shrinkage when it cools. This fact alone would bring into question the density of the final filling. However, Martin point out that the Schilder compaction method leads to 0.45% shrinkage, and since Endotec temperatures are lower than with the other technique, shrinkage following Endotec usage should be lower as well.

A US Army group evaluated the quality of the apical seal produced by lateral versus warm lateral compaction and found no significant difference in leakage. In contrast, Kersten, in Amsterdam, reported that “Endotec had significantly less leakage than any of four other methods.” Ewart and Saunders, in Glasgow, found much the same. A US Army group achieved the best result with the Endotec if they condensed the gutta-percha bolus five times with the cold plugger after each warming with the plugger heated. This practice filled lateral and accessory canals as well: “the gutta-percha was not melted but soft enough it would flow into fins and ramifications.” A US Army group reported they could improve the density (by weight) of laterally compacted canals by 14.63% by a follow-up.
use of the Endotec. A second use added another 2.43% of gutta-percha.429

As far as tissue reactions to the technique are concerned, Castelli et al. found that “some Endotec specimens generated small restrictive inflammatory infiltrates restricted to the root canal opening,” whereas the warm gutta-percha “vertical condensation inflammatory reactions, because of their extensive nature, were probably the source of maintaining discomfort and pain.”424

**Thermomechanical Compaction of Gutta-percha.** A totally new concept of heat softening and compacting gutta-percha was introduced by McSpadden in 1979. Initially called the McSpadden Compactor, the device resembled a reverse Hedstroem file, or a reverse screw design. It fit into a latch-type handpiece and was spun in the canal at speeds between 8,000 and 20,000 rpm. At these speeds, the heat generated by friction softened the gutta-percha and the design of the blades forced the material apically. In experienced hands, canals could be filled in seconds.

![Figure 11-66 Micro-Seal Gutta-percha Condenser](image)

However, problems developed and the Compactor fell into disfavor. Fragility and fracture of the instruments, along with overfilling because of the difficulty in mastering the technique, led to its demise. However, phoenix-like, it rose again in different shapes and forms. In Europe, Mallefer modified the Hedstroem-type instrument as the Gutta-Condenser, and Zipperer (Germany) called its modification the Engine Plugger. The latter more closely resembles an inverted K-file.

McSpadden, in the meantime, modified his original patent and brought out a newer, gentler, slower-speed model. It is now supplied as an engine-driven instrument made of nickel titanium (see Figure 11-66) and presented as part of the Microseal System (Analytic/Quantec, USA). Because of their flexibility, the NiTi condensers may be used in curved canals.

The Microseal Condenser is used in conjunction with heat-softened, alpha phase-like gutta-percha as well as regular gutta-percha points. Of course, sealer is always used. To obturate a canal, the clinician is advised to place the primary gutta-percha point, followed by the appropriate size Condenser (one that will reach near the working length), which has been coated with the heat-softened gutta-percha (Figure 11-67). The Condenser is spun in the canal with a controlled speed handpiece at 1,000 to 4,000 rpm to form a firmer core. This “flings” the gutta-percha laterally and vertically (Figure 11-68).

McSpadden has developed a technique to fill open-apex cases as well by initially depositing a bolus of low-heat gutta-percha at the apex with a large condenser. This is allowed to cool and harden to form an apical plug against which the remaining canal is obturated with gutta-percha points and additional heat-softened gutta-percha.430

To date, this particular technique—combining the reverse screw-type condenser with warmed alpha gutta-percha—has not been widely reported in US literature; however, the technique is popular in Europe, with some reporting from there.

**Efficacy of the Thermomechanical Compaction Method.** The original McSpadden compactor was well studied in the 1990s, and these findings are not totally moot because a modification is being distributed as the Brasselet TLC (Thermal Lateral Condensation) as well as the aforementioned European models, the Mallefer Gutta-Condensor and the Zipperer Engine Plugger. These instruments have enjoyed a good deal of use, particularly for "backfilling" after the initial vertical or lateral compaction is complete.

This latter method has been termed the **hybrid technique** by Tagger et al. of Tel Aviv.375 They first coat their
regular primary point with sealer, move it to place, and spread it aside with a finger spreader followed by an accessory point. They then place an Engine Plugger, size 45 or 50, 4 or 5 mm into the canal and rotate it at 15,000 rpm. After 1 second, it is advanced into the canal until resistance is met and then slowly backed out while still rotating. Only 2 or 3 seconds are involved to completely fill the canal.

Comparing the hybrid technique with lateral condensation, Tagger et al. reported significantly less apical leakage with the hybrid technique. They previously had reported no significant difference in leakage when they used thermomechanical compaction alone (not the hybrid technique) versus lateral compaction. Some agreed, whereas others found thermomechanical compaction improved the apical seal.

Saunders at the University of Dundee found that "the Hybrid method would be the technique of choice." He found that it was "quicker to complete than conventional lateral condensation, should carry a reduced risk of fracture to slender roots and is relatively easy to master." Overfilling is also less likely.

Concern has been expressed about the intracanal heat generated during thermomechanical compaction. Could it be damaging to the periodontium? Hardie at the University of Dundee recorded in vitro "rises in temperature up to 27°C" on the external midsection of roots. She voiced a need for caution if a 4-second appli-
cation of a spinning compactor could produce this much rise in temperature. Saunders, also at Dundee, performed in vivo hyperthermia studies on ferrets using an Engine Plugger at 10,000 rpm. He found a median 18.31°C temperature rise during use, which then dropped to a 1.25°C rise in 1 minute. He also examined these specimens histologically 20 days after testing and found resorption of cementum in 20% of the specimens. At 40 days he found about 25% exhibited resorption as well as ankylosis of bone to cementum and sounded a note of caution.

In Sweden, with workers using the compactor for 8 seconds, temperature increases as much as 50°C (35°C mean) were recorded. They, too, felt that “periodontal complications from thermomechanical condensation are possible.” At the University of Florida, a group stated that higher speeds or longer duration than recommended could “cause an adverse temperature rise…and a detrimental effect upon the quality of the seal.” These “outer-limit” studies lead one to conclude that care must be used, “kinder and gentler,” in any of these mechanical, heat-generating methods. On the other hand, they make a case for the less aggressive method: slower-speed, lower-temperature plasticized gutta-percha that can be placed with less stress to the tooth, yet provide optimal obturation.

Thermomechanical Solid-Core Gutta-percha Obturation. One other innovation using the thermomechanical principle to compact gutta-percha in the root canal has been introduced as the J.S. Quick-Fill (J.S. Dental Co., Sweden/USA). This system consists of titanium core devices that come in ISO sizes 15 to 60, resemble latch-type endodontic drills, coated with alpha-phase gutta-percha (Figure 11-69). These devices are fitted to the prepared root canal and then, following the sealer, are spun in the canal with a regular low-speed, latch-type handpiece. Friction heat plasticizes the gutta-percha and it is compacted to place by the design of the Quick-Fill core. After compaction, there are two choices: either the compactor may be removed while it is spinning and final compaction completed with a hand plugger or the titanium solid core may be left in place and separated in the coronal cavity with an inverted cone bur.

Pallares and Faus, from Valencia, Spain, conducted an apical leakage dye study comparing J.S. Quick-Fill against lateral condensation. They found no significant difference in efficacy; however, they did find with the J.S. Quick-Fill that the sealer (AH26) adapted more peripherally against the dentin walls and the gutta-percha was more centrally located. The cement had also penetrated the dentinal tubules and the lateral and accessory canals. Canalda-Sahli and his coworkers, also from Spain, found that J.S. Quick-Fill could be used successfully to seal root canals in teeth with large straight canals.

Ultrasonic Plasticizing. The technique of plasticizing gutta-percha in the canal with an ultrasonic instrument was first suggested by Moreno from Mexico. He used a Cavitron ultrasonic scaler (Dentsply/Caulk; Milford, Dela.) with a PR30 insert, but because of its design it could be used only in the anterior mouth. Moreno placed gutta-percha points to virtually fill the canal. He then inserted the attached endodontic instrument into the mass, activated the ultrasonic instrument (without the liquid coolant), and as it plasticized the gutta-percha by friction, advanced it to the measured root length. Final vertical compaction could be done with hand or finger pluggers.

At San Antonio, workers questioned the heat generated by this technique. Would it be damaging? Using the Cavitron PR30, they found very little heat rise: 6.35°C in 6.3 seconds. Using an Enac ultrasonic unit (Osada Co.; Los Angeles, Calif. and Japan), however, they recorded a

Figure 11-69 J.S. Quick-Fill titanium carriers coated with alpha-phase gutta-percha comes in four sizes and operates in regular slow-speed handpiece. Friction plasticizes gutta-percha. Titanium core may be severed and left or removed while still spinning. (Courtesy of J.S. Dental Mfg. Co.)
19.1°C rise in temperature because it took 141 seconds to plasticize the mass. They felt the heat generated by the Cavitron would not be harmful.441

At the University of Iowa, on the other hand, a group was quite impressed with a technique using an Enac ultrasonic unit (Osada) with an attached spreader. Unlike the University of Texas group, however, they did not attempt to plasticize the gutta-percha. They felt the spreader more easily penetrated the mass of gutta-percha than did the finger spreaders, and that in the end, the energized spreading technique led to a more homogeneous compaction of gutta-percha with less stress and less apical microleakage442 (Figure 11-70).

Thermoplasticized Injectable Gutta-percha Obturation. An innovative device, introduced to the profession in 1977, immediately caught the fancy of dentists interested in the compaction of warm gutta-percha. Developed by a group at Harvard/Forsyth Institute, gutta-percha was ejected out of a prototype pressure syringe that had warmed it to 160°C. At this temperature, the gutta-percha would flow through an 18-gauge needle.443 From this early model, a more efficient system was developed and patented.444,445 Today, through further improvements, the device is marketed as the Obtura II Heated Gutta-Percha System (Obtura-Spartan Corp., Fulton; Mo.) (Figure 11-71), with digitally controlled temperatures ranging from 160°C to 200°C while the needle size has been reduced to either 20 gauge (equal to a size 60 file) or 23 gauge (equal to a size 40 file) (Figure 11-72).

Although regular beta-phase gutta-percha is still used, the clinician can now choose a less viscous, higher flow form of gutta-percha known as Easy Flow (Charles B. Schwed Co.; Kew Gardens, N.Y.).

Gutmann and Rakusin, leading proponents of thermoplasticized gutta-percha obturation, have emphasized the importance of properly preparing the canal to receive the injection needle and compacting the warm gutta-percha. They point out the importance of preparing a “continuously tapering funnel from the apical matrix to the canal orifice.”446 They especially note the significance of properly shaping the transitional area from the apical third to the middle third, particularly in curved canals (Figure 11-73), and warn against the development of the “coke-bottle” canals so frequently seen following Gates-Glidden canal preparations (Figure 11-74). The tapered preparation enhances the flow of the plasticized material, whereas the Coke-bottle preparation negates the flow.446

A definitive apical matrix is also important. This constriction prevents the extrusion of filling material into the periapex (see Figure 11-73). Preparations to size 25 or 30 files at the apical terminus, tapered to a size 60 file at the coronal orifice, have proven perfectly
adequate as long as there is sufficient blending of the coronal preparation with the apical preparation.

**Methods of Use.** Although initially it was hoped that the “gutta-percha gun” could be used to totally obturate the canal, it soon became apparent that sealer and further compaction were necessary. Sealer serves its usual role of filling the microscopic interface between the dentin and gutta-percha as well as acting as a lubricant. Compaction became necessary to close spaces and gaps while forcing the gutta-percha laterally and vertically. It also compensates for shrinkage as the gutta-percha cools. Furthermore, the smallest injection needle, 23 gauge, was too large to reach the apex in most cases.

Initially, a technique was developed of depositing the warm plasticized gutta-percha well down into the canal and then compacting it with hand or finger pluggers to the apical terminus. In using this method, however, one must be prepared to act as soon as the gutta-percha is placed because it cools rapidly and hardens, often within 1 minute; however, the Easy Flow gutta-percha does afford at least 10 to 15 more seconds of working time.
The injection needle and pluggers must have been previously tried for size in the canal. Although the manufacturer recommends that they should reach within 3.5 to 5 mm of the terminus and fit loosely at that point, sufficient compaction can still occur as long as the needle reaches halfway between the canal orifice and apical terminus in a well-prepared canal. In fact, Lambrianidis and coworkers in 1990 demonstrated that there was no statistically significant difference in linear dye leakage in Obtura-filled canals in which there were varying distances of the needle tip from the apical foramen during obturation.447 Regardless of whether a sectional technique is used or a complete filling method is used, silicone stops are placed on pluggers of adequate diameter to ensure they will move and compact the softened material and not just “pierce” through it.

A light liner of a slow-setting sealer is placed into the dried canal to the prechosen depth short of the apex. Excessive sealer causes pooling and should be avoided. Sealers such as Roth's 801, AH Plus, or Sealapex are recommended. This is followed by the Obtura needle, and a deposit of gutta-percha is made. The canal may be totally filled as the needle is withdrawn, or a small deposit may be made and compacted with the intention of filling the canal segmentally.

Research by Johnson and Bond at Louisiana State University showed no difference in dye penetration in canals that were backfilled with 1 mm, 4 to 5 mm, or 10 mm increments irrespective of whether Roth's 801 or AH26 sealer was used.448 However, the clinician probably has better control of moving and compacting gutta-percha when segmental filling is done.

Once the deposit is placed, the premeasured plugger is rapidly used to move the gutta-percha apically and laterally. A drop of sealer on the tip of the plugger will prevent its adhering to the gutta-percha. When one is satisfied that the apical third is obturated, a quick radiograph or digital image can be made to ensure the placement. Once viewed, the obturation may be completed.

If the filling is short, gutta-percha, if now firm, may be warmed with a hot instrument and then further compacted; the bolus may also be completely removed and the canal refilled. In this event, one may warm the tip of a Hedstroem file, insert it into the gutta-percha, let it cool for 1 minute, and then remove the bolus of gutta-percha. Refilling of the canal can then be done, this time inserting the pluggers to a greater depth, using Easy Flow gutta-percha and/or repreparing the canal first. The radiograph of the final result should show a thoroughly compacted, totally obturated reflection of the tapered canal preparation (Figure 11-75).
Another popular obturation method used by many endodontists is to initially place a fitted master point to the apical terminus and follow this with the Obtura needle-tip, depositing a bolus of warm gutta-percha around the point. This is immediately compacted vertically and laterally. More plasticized gutta-percha is then added and compacted. This technique will better ensure apical closure without overfilling.

Success with any of these techniques is operator dependent. Repeated practice on plastic-block canals as well as extracted teeth is imperative. To gain intraoral experience, one might start by using the device to backfill other methods before tackling full-treatment cases and by initially using the system on large, relatively straight canals. As a matter of interest, the Obtura II is probably being used more frequently as a backfilling device than for primary obturation.

Efficacy and Safety of the Thermoplastic Injectable Gutta-Percha Technique. A number of studies on the heat generated by this method have been done. Gutmann et al. found in vitro that the gutta-percha emerged from the needle at 71.2°C in a body temperature environment.449

In an in vivo study on dogs, the mean intracanal temperature of the gutta-percha was 63.7°C. Maximum temperature elevation on the bone overlying these test teeth was only 1.1°C over 60 seconds. This appears to be a safe temperature level.450

Others recorded much higher (137.81°C) intracanal recordings.451 Hardie recorded a temperature rise of 9.65°C on the external surface of a tooth.452 This dropped to 4.75°C in 3 minutes and compared with a 15.38°C rise in temperature generated by an Engine Plugger compactor spinning at 8,000 rpm.452 Bone injury has been reported with external root temperature rises of 10°C if maintained for 1 minute.453 Hardie’s reported 9.65°C increase (dropping to 8.20°C in 1 minute) appears to fall within safe limits.452 Weller and Koch evaluated external root temperatures in vitro when using gutta-percha thermoplasticized at 200°C and additionally found that the rise in temperature was well below the critical level of 10°C.454

The efficacy of thermoplasticized gutta-percha in filling fins and cul-de-sacs,455 internal resorption cavities,436,457 “C”-shaped canals, accessory canals, and arborized foramina is well documented (Figure 11-76). All researchers insist, however, that sealer is necessary to prevent microleakage.437,458 Clinical success rates with the injection technique have been reported at 93.1%.459

Compared with other techniques, the thermoplasticized, regular beta-phase (higher heat) gutta-percha...
proved equal to laterally compacted cold gutta-percha in a number of studies of microleakage\textsuperscript{362–364} and significantly poorer in others.\textsuperscript{347,348} Virtually all of the studies reported some overfilling and apical extrusions.\textsuperscript{347,348,362,363} At least one author admitted, however, that his group’s results “confirmed the opinion of Gutmann and Rakusin that clinicians should take time to master the technique before employing it in the treatment of their patients.”\textsuperscript{347} As with any obturation technique, the efficacy and long-term success of the method are highly dependent on the cleaning and shaping of the canal and the resultant degree of retention and resistance form that is developed.

**Inject-R Fill–Backfilling Technique.** As stated earlier, the Obtura II is frequently used in “backfilling,” a method for completing total canal obturation after the apical third of the canal has been filled. Another method of backfilling has been developed by \textit{Roane} at the University of Oklahoma and is marketed as \textit{Inject-R Fill} (Moyco-Union Broach; Bethpage, N.Y.).

\textit{Inject-R Fill}, a miniature-sized metal tube containing conventional gutta-percha and plunger, simplifies warmed vertical compaction by altering the backfilling process. The technique allows for delivery of a single backfill injection of gutta-percha once the apical segment of a canal has been obturated (Figure 11–77).

The apical segment of the canal can be obturated using any technique including lateral compaction, traditional warm vertical compaction, or System B. If a cold lateral technique is used, the cones of gutta-percha extruding from the canal must first be heat severed at a sufficient depth so a plugger can be used to compact the remaining heat-softened segment in the apical third of the canal. If the System B or vertical compaction is used, the method already results in an apically compacted segment.

According to the \textit{Inject-R Fill} technique, the coronal walls must be resealed with sealer prior to filling the region with gutta-percha from the device.\textsuperscript{460} The \textit{Inject-R Fill} must first be heated in a flame or an electronic heater and the coronal surface of the gutta-percha already in the canal should be warmed using a heated instrument. When a burner is used, the stainless steel gutta-percha filled sleeve is waved through the flame until gutta-percha \textit{begins to extrude} from the open end. The warmed unit is then placed into the orifice of the canal. For the device to fit, the canal orifice must be at least 2 mm in diameter. A push of the handle toward the canal injects the heated gutta-percha into the canal. The carrier is then rotated to break it free from the access.

\textit{Prefitted} hand or finger pluggers are subsequently used to compact the gutta-percha and push the injected mass into contact with the apical segment. The plugger must be positioned in the center of the mass and pressed firmly toward the apex. Pressure is sustained for a few seconds before the plugger is rocked from side to side and rotated to break it free. As the plugger is removed, a small void is left in the center of the mass. The void is closed by folding over remaining gutta-percha from the sides and packing it apically. This process is repeated until a larger plugger can be used without creating a void and the gutta-percha mass is firm. Coating the tip of each \textit{Inject-R Fill} with sealer before placing it in the canal will prevent sticking of the gutta-percha and should enhance the gutta-percha/sealer/canal interface. According to Roane, the technique is rapid and produces a result similar to that of warm vertical compaction (personal communicaton, April 2000).

An important caveat must be issued, warning anyone using a system of injection, thermoplasticized gutta-percha—be very careful not to force or overinject the heat-softened material.\textsuperscript{461} Disastrous results may develop if, for example, the softened gutta-percha is injected into the maxillary sinus or the inferior alveolar canal (Figure 11–78).

**SOLID-CORE CARRIER: MANUAL INSERTION**

\textit{ThermaFil} (Dentsply/Tulsa), \textit{Densfil} (Dentsply/Maillefer), \textit{Soft-Core} (Soft-Core System, Inc.), and \textit{Three Dee GP} (Deproco UK Ltd.)

In 1978, Johnson described a unique yet simple method of canal obturation with thermoplasticized...
alpha-phase gutta-percha carried into the canal on an endodontic file. What was a curiosity in 1978 has become today a popular and respected technique of canal obturation (Figure 11-79). ThermaFil is considered the major core-carrier technique, and through a licensing agreement with Dentsply, a duplicate product, Densfil was created. Recently, two similar products were introduced: Soft-Core, and its European version, Three Dee GP.

“ThermaFil is a patented endodontic obturator consisting of a flexible central carrier, sized and tapered to match variable tapered files (.04/.06) endodontic files. The central carrier is uniformly coated with a layer of refined and tested alpha-phase gutta-percha.” The use of the variable tapered files in canal preparation has enhanced the fit, placement, movement, and compaction of the gutta-percha delivered by the ThermaFil core carrier. Likewise, the ThermaFil system now

Figure 11-78  A, Plasticized gutta-percha extruded from syringe overfills enormous area of mandible. B, Pathologic specimen of osteomyelitic bone and chronic inflammation attached to extruded gutta-percha. Reproduced with permission from Gatot A et al.461

Figure 11-79  A, Original handmade gutta-percha obturator mounted on regular endodontic file. B, Modern manufactured Thermafil Obturators—alpha-phase gutta-percha mounted on radiopaque, flexible, plastic carriers. Note silicone stop attachments. A reproduced with permission from Johnson WB.462 (B courtesy of Dentsply/Tulsa Dental Products.)
comes with metallic size verifiers that are used to
determine, with greater precision, the size and shape of
the prepared canal prior to choosing the correct
ThermaFil carrier.

Initially, the central carrier was a newly designed
stainless steel device. Contemporary carriers are made
of radiopaque plastic that is grooved along 60 degrees
of their circumference (Figure 11-80). While the
gutta-percha covering the original carriers was heated
in a flame, the new plastic core carriers are heated in a
controlled oven environment called the ThermaPrep
Plus heating system (Dentsply/Tulsa; Tulsa, Okla.)
(Figure 11-81). The heating time is well delineated and
is dependent on the size of the core carrier. The use of
the oven, according to the manufacturer’s directions, is
essential for success with this technique.

Soft-Core, or its counterpart, Three Dee GP, is sim-
ilar to ThermaFil; however, it contains a bipolymer
compound and a tungsten core that is radiopaque. It
has an easily detachable handle, referred to as a metallic
insertion pin, that is removed with a slight twisting
action. This leaves the coronal portion of the plastic
core hollow, thus facilitating postspace preparation.
The presence of the metallic insertion pin also allows a
curving of the coronal portion of the carrier, thus facil-
ilitating the angle of core insertion. It is supplied in a
sterile blister pack that also contains a matching size
verifier. The carriers are thinner in taper than the
ThermaFil carriers but are ISO sized at the apex. This
was done to facilitate their use in small canals that are
difficult to shape. Heating of the gutta-percha on the
Soft-Core carrier is done in a halogen oven that is ther-
mostatically controlled.

Method of Use. The detailed use of the core carrier
obturation technique has evolved after years of develop-
ment and clinical use.464 Careful cleaning and shaping of
the canal are essential, as is the development of a con-
tinuously tapering preparation. Contemporary dictates
favor the use of the variable tapered endodontic files
to achieve this goal and to enhance the obturation afforded
by the ThermaFil technique.

Prior to obturation, it is recommended that the smear
layer be removed with the appropriate agents. This will
promote the movement of the softened material into the
dentinal tubules and enhance the seal.465 After the canal
is dried, a very light coat of sealer is applied to all of the
walls. It acts as an adhesive as well as a lubricant.
Preferred sealers include Thermaseal (Dentsply/Tulsa;
Tulsa, Okla.), AH-Plus (Dentsply/Maillefer; Tulsa, Okla.),
Sealapex (Kerr/Analytic; Orange, Calif.), or ZOE
cements. Quick-setting cements such as Tubliseal, or
cements that contain natural gutta-percha softeners, such
as Sealex or CRCS, should be avoided with this tech-
nique. In the case of the former, the sealer sets up too rap-
ida when warmed. In the case of the latter, the chemical
softening of the gutta-percha makes it too tacky and
adherent to the dentin walls, thereby reducing its flow
apically and into the canal irregularities.

Immediately after the sealer is applied, the warmed
obturator is removed from the ThermaPrep Plus heater
and carried slowly to full working length in the canal.
Previously, the built-in rubber stop, on the calibrated shaft, had been set at the proper length position. The carrier is not twisted during placement, and attempts to reposition the carrier should be avoided to prevent disruption of the gutta-percha that was initially positioned through the compacting action of the core carrier.

Once it is ensured radiographically that the canal has been filled to the desired position, the shaft is severed in the coronal cavity. While the handle is firmly held aside, a No. 37 inverted cone bur is used to trim off the shaft 2 mm above the coronal orifice. Specific burs have also been developed for this task: Prepi Bur (Prepost Preparation Instrument) (Dentsply/Tulsa; Tulsa, Okla.). The Prepi Bur, a noncutting metal ball, is run in a handpiece and is also used to create postspace safely and efficiently when needed. This space can be created immediately or on a delayed basis without altering the apical seal.

Johnson has suggested that the final compaction can be improved if a 4 to 5 mm piece of a regular gutta-percha cone is inserted into the softened gutta-percha and compacted apically and laterally with a large plugger. Gutta-percha accessory points can also be used in a similar fashion to achieve a greater depth of material delivery if the canal is very wide buccolingually. In this case, an appropriately sized spreader would be used to compact the cones into the softened mass. The use of warm injected gutta-percha by Obtura (Obtura/ Spartan, USA) is also an accepted technique to add sufficient bulk to the obturating material. The gutta-percha reaches its final set in 2 to 4 minutes.

**THERMAFIL SAFETY**

Saw and Messer from Australia evaluated and compared the root strains associated with the compaction of gutta-percha delivered from the Obtura and ThermaFil with lateral compaction. The ThermaFil technique required only minimal compaction that was limited to the coronal end of the carrier. Therefore, with this technique there was significantly less strain during delivery and compaction than there was with the other tested techniques.

An apical stop or definitive apical constriction must be present to prevent movement of the gutta-percha and/or the plastic core from extending beyond the root canal. Often, a small puff of sealer or gutta-percha will be extruded. A US Army group found that ThermaFil was more apt to extrude through a patent apical foramen than was Obtura, Ultrafil, or warm lateral compaction (Endotec). On the other hand, if a dentin “plug” was present at the apical orifice, ThermaFil was less apt to extrude than were the other obturators. The use of the size verifiers in choosing the correctly sized core carrier has also reduced the incidence of material overextension.

The precurving of ThermaFil obturators is usually not necessary if the canal is prepared properly, as the flexible carrier will easily move around curves. With this technique, gutta-percha will flow easily into canal irregularities such as fins, anastomoses, lateral canals, and resorptive cavities (Figure 11-82).

**Efficacy of ThermaFil Obturation.** A nationally recognized evaluator of materials, devices, and techniques, Clinical Research Associates (CRA), headed by Christensen, has indicated that “ThermaFil allows simple, fast, predictable filling of root canals. It was found to be especially useful for small or very curved canals.” Radiographic assessment of this gutta-percha delivery technique has been quite favorable, and recent adaptation studies that have looked at the contemporary use of the technique have found it comparable to, if not better than, lateral compaction.

Gutmann et al. and W. P. and E. M. Saunders from Glasgow evaluated ThermaFil versus lateral compaction in a series of studies. They reported that “ThermaFil resulted in more dense and well adapted root canal fillings throughout the entire canal system than lateral condensation with standard gutta-percha.” Both techniques “demonstrated acceptable root canal fillings in the apical one-third of the canal.” Similar excellent adaptation was observed when comparing ThermaFil with the System B technique. However, the gutta-percha from the ThermaFil carrier did show a greater propensity to extrude beyond the apex.

Wolcott and coworkers, in an in vitro study at Tennessee, found that the movement of ThermaFil gutta-percha and sealer into lateral canals was comparable to lateral compaction; however, the Thermafil was more effective in the main canal. Weller et al. at Georgia used a split-tooth model to assess gutta-percha adaptation using Obtura, three types of ThermaFil core carriers, and lateral compaction. No root canal sealer was used. The best adaptation was with Obtura obturations, followed by ThermaFil plastic, ThermaFil titanium, ThermaFil stainless steel, and lateral compaction. Of interest in this study was the lack of apical extrusion noted with the ThermaFil obturations.

In assessing leakage patterns with the contemporary ThermaFil technique, Gutmann and W. P. and E. M. Saunders found initially “no significant differences in leakage between the techniques.” At 3 to 5 months, however, both techniques revealed apical microleakage. On the other hand, “ThermaFil obturations demonstrated greater adaptation to the intricacies of the canal
system.” Fabra-Campos reported much the same from Spain. Using plastic-carrier ThermaFil and lateral compaction, Pathomvanich and Edmunds from Wales used four different leakage methods and found no difference in the leakage patterns with any of the evaluative techniques, nor was there any difference between lateral compaction and ThermaFil. Valli and coworkers compared Densfil (ThermaFil look-a-like) obturations with lateral compaction in canals that were prepared with hand instruments. While the Densfil obturations showed less mean apical leakage (1.39 mm) than lateral compaction (2.76 mm), the data were not significant. Similarly, they also compared the coronal leakage with both techniques, with the mean coronal leakage for Densfil being 2.87 mm and the mean coronal leakage for the lateral compaction being 4.028 mm, but no statistically significant differences were noted.

Most recently, both short- and long-term leakage comparing ThermaFil with System B in the absence of the smear layer was reported by Kytridou et al. There were no significant differences in the short-term leakage patterns (10 and 24 days); however, leakage at 67 days was greater in the ThermaFil group. Unlike other studies, however, these specimens were stored in Hanks Balanced Salt Solution to better simulate the periradicular tissue fluid environment.

Silver Point Technique. Another solid-core material of long standing (but not in good standing) is the silver point technique. Despite nearly universal disapprobation, there are uses for silver points. The fault lies not in the point but in the execution. The cavity prepared to receive the point must be as perfectly rounded and tapered as the point itself. “It must fit like a cork in a bottle.” Too often, round silver points are cemented into ovoid canals. Over the years, as the sealer surrounding the point gradually dissolves away, microleakage and a subsequent periradicular lesion develop.

With all of the other techniques available, why use silver points at all? They are very easy to use in narrow canals. They are rigid, yet flexible, and can be positioned rapidly. Ingle has pointed out that “…When properly cemented to place, they provide a perfectly adequate filling for the geriatric patient at a real time saving.” He further noted that the very elderly have a limited life expectancy, and that silver points, even improperly done, have been known to last over 20 years. Treatment for a 75-year-old patient may be somewhat different than that for a 25-year-old patient.

Furthermore, secondary dentin formation narrows the canal lumen in “ancient” teeth, lending them to preparation by reaming. “Good candidates would be the straight round canals in upper central incisors, or

Figure 11-82 Obturation with Thermafil. A, Central incisor filled with size 60 Thermafil Obturator—plastic carrier. Note lateral canal near apex. B, Both mesial and distal canals filled with size 45 Thermafil Obturators—plastic carrier. Note apical fill and lateral canal. (Courtesy of Dr. W. Ben Johnson.)
the two canals in upper first premolars, or a straight palatal canal in an upper first molar, or a straight distal canal of a lower first molar. Occasionally, even buccal canals in upper molars, upper canines, or mesial canals in lower molars qualify if they are straight.\textsuperscript{478}

These might well be cases in which the final apical preparation can best be done with one of the new reamer-type instruments: the Handy-Gates (Dentsply/Maillefer; Tulsa, Okla. and Switzerland) or the LightSpeed (LightSpeed Tech., Inc.; San Antonio, Tex.). In any event, “the silver point baby need not be thrown out with the bath.”

**APICAL THIRD FILLING**

SimpliFill Obturation Technique

SimpliFill is a relatively new, two-phased obturation method that advocates the use of a stainless steel carrier to place and compact a 5 mm segment of gutta-percha into the apical portion of a canal (Figure 11-83).

Once placed, the carrier is removed, leaving a plug of gutta-percha. If a post is not desired, the second phase uses a specially designed syringe to backfill the remaining portion of the canal with Ketac-Endo sealer along with accessory cones of gutta-percha. The clinician can also choose any other method to backfill the remaining portion of the canal. According to the manufacturer, the overall advantages of SimpliFill are that its use helps conserves dentin because of the Lightspeed instrumentation technique (less flaring); it eliminates additional internal forces since no spreader or plugger is used to compact the apical plug; it is simple to master; and, in contrast to other core-carrier systems, no carrier is left in the canal.

SimpliFill was originally developed by Senia at Lightspeed Technology to complement the canal shape created using Lightspeed instruments. The Apical GP Plug size is the same ISO size as the Lightspeed “Master Apical Rotary” (MAR) (see Chapter 10).

Following the completion of canal preparation using rotary Lightspeed, the specially designed Apical GP Plug Carrier corresponding to the MAR is trial fitted without sealer into the dry canal. Before insertion, however, the rubber stopper on the carrier, with its attached gutta-percha, is set 2 mm short of the working length. The carrier is then inserted into the canal and slowly advanced, until it should start to bind at the length indicated by the rubber stop (ie, 2 mm short of the working length). Once the fit has been verified, the Apical Plug carrier is removed and the canal is coated with an appropriate sealer using the MAR or a sealer saturated paper point. The rubber stopper on the carrier is now advanced 2 mm to the working length. The GP Plug is subsequently coated with sealer, inserted in the canal, and advanced until resistance is felt, about 2 mm short of the working length. Using the carrier, the GP Plug is now vertically compacted to the working length with firm apical pressure. The carrier must not be rotated during insertion or compaction. Once the GP Plug is snugly fit, the GP Plug is released by rotating the carrier handle counterclockwise. During this rotation, the carrier must not be pushed or pulled. If the GP Plug does not release, the carrier sleeve is grasped with cotton pliers and, while pushing apically on the sleeve, the handle of the carrier is rotated counterclockwise and withdrawn.

Phase two consists of backfilling the remaining canal if no post is desired. The clinician has a number of options for backfilling, including the method advocated by the manufacturer described as follows. A SimpliFill syringe is loaded with a sealer such as Ketac-Endo and the sealer is slowly injected into the canal space as the tip of the needle, equivalent to size #40 file, contacts the GP Plug and is slowly withdrawn. Inserting the needle all the way to the top of the plug will help eliminate formation of air bubbles during the backfill. An ISO standardized gutta-percha cone, equivalent in size to the Apical GP Plug used to fill the apical segment, is then coated with sealer and placed into the sealer-filled canal until it contacts the compacted GP Plug. Accessory gutta-percha cones can be added as space fillers. As stated earlier, the clinician can also backfill using traditional warm-vertical compaction or may simply backfill using the Obtura II.

Since the technique is so new, there was only one published study. In 1999, Santos and coworkers at the

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Figure 11-83  SimpliFill apical gutta-percha plug. Point is lightly heated and used as primary apical fill. Carrier is twisted for removal and used as plugger. (Courtesy of LightSpeed Technol.)
University of Texas at San Antonio evaluated the prototype sectional method (SimpliFill) and compared it to laterally compacted gutta-percha.\textsuperscript{479} In their study, single canal teeth were prepared using Lightspeed and were subsequently obturated using three methods: lateral gutta-percho compaction with Ketac-Endo sealer, lateral compaction with Roth’s 801 sealer, or the SimpliFill sectional method with Ketac-Endo sealer followed by a single cone of gutta-percha in Ketac-Endo sealer as backfill. Using India ink to measure leakage, they found no statistically significant difference in apical microleakage among the three groups. In addition, it was noted that the sectional method was significantly faster than lateral compaction.\textsuperscript{479} Although the technique appears promising, further studies will be necessary along with clinical trials to determine the long-term efficacy of the SimpliFill system.

Dentin Chip Apical Filling. A method finding increasing favor, and one that inadvertently happens more often than not, is the apical dentin chip plug, against which other materials are then compacted. Quite probably, some of the so-called “miraculous cures” occur apically, to prepared but unfilled canals, because the apical foramen have actually been obturated by dentin chips from the preparation.\textsuperscript{480} To do this deliberately constitutes the “new technique,” a “biologic seal” rather than a mechanochemical seal.

The premise that dentin fillings will stimulate osteo or cementogenesis is well founded. Gottlieb and Orban noted cementum forming around dentin chips in the PDL as early as 1921. The German literature is replete with this method. Mayer and Ketterl filled 1,300 canals with apical dentin chips and reported 91% success.\textsuperscript{481} Ketterl later reported 95% success with cementum-like closure at the apex.\textsuperscript{482} Waechter and Pritz also reported “osteocementum” apical closing in 20 human cases.\textsuperscript{483} Baume et al. described “osteodentin” closings but incomplete calcification across all of their histologic serial sections.\textsuperscript{484}

More often than not, dentin chip obturation undoubtedly prevents overfilling. El Deeb et al. found exactly that: “The presence of the apical dentinal plug,” they stated, “was significantly effective in confining the irrigating solutions and filling materials to the canal space.”\textsuperscript{485} This same conclusion was reached by Oswald et al., who observed that dentin chips lead to quicker healing, minimal inflammation, and apical cementum deposition, even when the apex is perforated\textsuperscript{486} (Figure 11-84). Holland et al., from Sao Paulo, found, however, that dentin chips, if infected, are a serious deterrent to

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\textbf{Figure 11-84} Dentin chip root canal plug after 3 months. \textbf{Left}, Periradicular area. B, bone, C, cementum, DP, dentin plug.\textbf{Arrows} indicate canal wall. \textbf{Right}, High-power view of same periradicular area. C, cementum within canal around dentin chips (arrows). OB, new bone cells. Reproduced with permission from Oswald RJ and Friedman CE.\textsuperscript{486}
healing, and Torneck et al. found that some dentin chips may actually irritate and hinder repair.

Method of Use. The dentin chip technique has been used and taught at the Universities of Oregon and Washington (J. Marshall, personal communication, July 26, 1981; G. Harrington, personal communication, August 13, 1982). After the canal is totally debried and shaped and the dentin no longer “contaminated,” a Gates-Glidden drill or Hedstroem file is used to produce dentin powder in the central position of the canal (Figure 11-85, A). These dentin chips may then be pushed apically with the butt end (Figure 11-85, B) and then the blunted tip of a paper point (Figure 11-85, C). They are finally packed into place at the apex using a premeasured file one size larger than the last apical enlarging instrument (Figure 11-85, D). One to 2 mm of chips should block the foramen (G. Harrington, personal communication, August 13, 1982). Completeness of density is tested by resistance to perforation by a No. 15 or 20 file. The final gutta-percha obturation is then compacted against the plug (Figure 11-86).

Japanese researchers found they could totally prevent apical microleakage if they injected 0.02 mL of Clearfil New Bond dentin adhesive (J. Morita, Japan) into the coronal half of the dentinal apical plug. Harrington points out that a dentin plug is de rigueur if the apical foramen is perforated or open for any reason (G. Harrington, personal communication, August 13, 1982). In flaring the wall to produce dentin chips, care must be taken not to thin the walls excessively.

Efficacy of Dentin Chip Apical Obturation. As stated earlier, one of the positive effects of a dentin plug filling is the elimination of extrusion of sealer or gutta-percha through the apex. This reduces periradicular inflammation. It also provides an apical matrix against which gutta-percha is compacted. The group at the University of Connecticut found, however, that they could not totally block the apical foramen with chips following vital pulpectomy in baboons. On the other hand, they did report “...hard tissue formation was common but no total closure occurred,” and that “...tissue response to dentin chips was generally favorable.”

In a monkey study at Indiana University, no attempt was made either to form or avoid forming a dentin plug. It was found, however, that 77% of 43 cases had demonstrable plugs. It was further reported that teeth with plugs “had a significantly lower frequency of [periradicular] inflammation than teeth without plugs ($p = 0.02$).” Although not a consistent finding, “new cementum was observed adjacent to dentin filings” (Figure 11-87). However, in this experiment, the dentin plugs were not purposely produced. Also, residual pulp tissue was sometimes present.

Another monkey study done at Loma Linda University indicated that the inorganic component of dentin, hydroxyapatite, is evidently the principal stimulant in producing more hard tissue formation and less inflammation than are fresh dentin chips or demineralized dentin.
After previously noting that infected dentin chips hindered periradicular healing, Holland et al. compared the cementogenesis and inflammation between dentin chips and calcium hydroxide. They found that dentin chips were responsible for thicker cementum formation but that overall there was no discernible difference between the two materials in ferrets.

The group at the University of Washington, in a smaller study, found that “the dentin plugs were more complete than those observed with calcium hydroxide.” No inflammation was present after 1 month. Both materials worked equally well to control the extrusion of the filling material; however, the calcium hydroxide tended to wash out quickly.

Returning to the original German studies, through the reports by Erasquin in 1972 and Tronstad in 1978, and including more recent reports, one must conclude that the dentin chip apical plug is a valuable contribution to endodontic success and deserves to be more widely used.

**Calcium Hydroxide Apical Filling.** Cementogenesis, which is stimulated by dentin filings, appears to be replicated by calcium hydroxide as well (Figure 11-88). Dentists have long observed the dramatic repair that occurs at the apex of a wide open canal of a tooth whose pulp was destroyed by trauma. Removing the necrotic canal contents and bacterial flora, thoroughly debriding

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**Figure 11-87** Dentin plug-induced cemental formation. Band of cementum (C) is seen adjacent to dentin plug (P). Periodontal ligament (L) is normal. Reproduced with permission from Patterson SM et al.

**Figure 11-88** Periradicular repair following intracanal application of calcium hydroxide. A, Low-power view of periapex. Acute inflammatory resorption of dentin and cementum following pulpectomy. Canal filled with calcium hydroxide mixture (CH). New hard tissue forming across apex in response to Ca(OH)₂. B, Higher-power view of repair leading to apical “cap” (arrow). (Courtesy of Dr. Billie Gail Jeansonne.)
the dentin walls, disinfecting the space, and totally filling the canal with calcium hydroxide, will practically ensure apexification (Figure 11-89). The same phenomenon applies to the closed apex—cementification reacting to the placement of a plug of calcium hydroxide. This is also the theory behind the calcium hydroxide-containing sealers that appear to be better in theory than in practice.507

As noted previously, calcium hydroxide resorbs away from the apex faster than do dentin chips.496 However, Pissiotis and Spångberg noted that calcium hydroxide mixed with saline resorbed but was replaced by bone in mandible implant studies.508

Method of Use. Calcium hydroxide can be placed as an apical plug in either a dry or moist state. Dry calcium hydroxide powder may be deposited in the coro-

Figure 11-89  Apexification of pulpless incisor with periradicular lesion. A, Preoperative film. B, Calcium hydroxide and camphorated monochlorophenol filling canal and extruding through apex. C, Nine months later, canal filled with sealer, softened gutta-percha, and heavy vertical compaction. No overfilling. D, Two-year recall. (Courtesy of Dr. Raymond G. Luebke.)
nal orifice from a sterilized amalgam carrier. The bolus may then be forced apically with a premeasured plugger and tapped to place with the last size apical file that was used. **One to 2 mm** must be well condensed to block the foramen. Blockage should be tested with a file that is one size smaller.

Moist calcium hydroxide can be placed in a number of ways: as described earlier with amalgam carrier and plugger, with a Lentulo spiral, or by injection from one of the commercial syringes loaded with calcium hydroxide: *Calasept* (J.S. Dental Prod., Sweden/USA) or *TempCanal* (Pulpdent Corp.; Boston Mass.). In the latter method, the calcium hydroxide paste is deposited directly at the apical foramen from a 27-gauge needle and is then “tamped” to place with a premeasured plugger. If some escapes, no great damage occurs. Because of time constraints in military dentistry, a US Air Force group recommended compacting a plug of dry calcium hydroxide powder at the open apex and immediately placing the final root canal filling.492

In a comparison of techniques for filling entire small curved canals with calcium hydroxide, the University of North Carolina group found the Lentulo spiral the most effective, followed by the injection system. Counterclockwise rotation of a No. 25 file was the least effective.510 If the calcium hydroxide deposit is thick enough and well condensed, it should serve not only as a stimulant to cemental growth but also as a **barrier to extrusion** of well-compacted gutta-percha obturation.

**Efficacy of Calcium Hydroxide Apical Obturation.** The University of Washington group reported good results with calcium hydroxide plugs. Both calcium hydroxide and dentin chips worked equally well controlling extrusion of filling materials. Although “…both plugs resulted in significant calcification at the foramen…the dentin plugs were complete…” No significant difference in periradicular inflammation was noted.496 However, Holland noted persisting chronic inflammation and a wide variance in hard tissue deposition.495 One would suspect contamination by oral bacteria compromised his results.

A University of Alabama group tested for microleakage canals filled by lateral compaction but blocked at the apex with three forms of calcium hydroxide: calcium hydroxide-USP, *Calasept*, or *Vitatex* (DiaDent Group International; Burnaby, B.C., Canada). There was no significant difference in leakage among the three forms of calcium hydroxide.511 Weisenseel et al. confirmed much the same, stating that “…teeth with apical plugs of calcium hydroxide demonstrated significantly less leakage than teeth without apical plugs.” All were filled with laterally compacted gutta-percha.512

**INJECTION OR “SPIRAL” OBTURATION**

By all accounts, filling the entire root canal by injection, or pumping, or spiraling material into place has great appeal. Unfortunately, the methods fall short, either because the technique is inappropriate or the materials used are inadequate.

Already discussed are the deficiencies encountered when warm gutta-percha is injected from one of the syringes to fill the entire canal. These inadequacies are caused by shrinkage from the heated to the cooled state, by failure to compact and eliminate voids, or by extrusion—serious overfilling.

An earlier favorite method of filling the canal with chloropercha and pumping it into place with gutta-percha points failed because of the severe shrinkage from chloroform evaporation.383 This method was followed by totally filling the canal with injected ZOE cement, which will provide an immediate seal, but is often subject to dissolution and leakage over the years, leading to eventual failure.

Fogel tested five sealers placed in canals with a pressure syringe. After 30 days, he found that AH-26, Cavit, Durelon, and ZOE cement all exhibited microleakage, although AH-26 had the least marginal leakage and was the easiest to manage.513

The fate of totally obturating canals with cements alone using a Lentulo spiral was sealed when a number of disasters of gross overfilling with N2 or RC2B were reported. The material itself could hardly be blamed, even though it is quite toxic. Rather, the blame falls on the dentist misusing the device in a spinning handpiece (Figure 11-90). The Lentulo spiral will also cause **underfilling** if not carefully monitored (Figure 11-91).

One possible exception to the dangers and foibles of injecting filling material into the root canal may lie with the emerging hydroxyapatite as an obturant. In this case, the calcium phosphate powders are mixed with glycerine and the paste is injected into the canal. The moisture left in the canal and the apical moisture cause the paste to set to hydroxyapatite. If the material is extruded, it resorbs and will be replaced by bone. Admittedly, neither the technique nor the product have been thoroughly researched to date.137,138,163,164

**DOWEL OR POST PREPARATION: POSSIBLE LEAKAGE**

Once again, what comes out of the canal may be more important than what goes in. In this case, it is the removal of a coronal portion of the root canal filling to accommodate post or dowel placements.
At Louisiana State University, two studies have been carried out examining the method of gutta-percha removal, the sealant used for obturation, and the length of the interval between obturation and the removal of gutta-percha to form the “posthole.”

The three removal methods were as follows:

1. Use of a hot plugger
2. Use of Peeso reamers
3. Use of chloroform and K-files

The results are very interesting: the method of removal did not seem to particularly affect the leakage results, whereas the time of removal was quite significant. If a hot plugger is used, the best results are achieved if the posthole gutta-percha is removed immediately after obturation. If Peeso reamers or chloroform and K-files are used, however, the removal should be delayed 1 week to allow for the final set of the cement sealer. Conjecture is that the hot plugger served immediately as a form of vertical condensation, improving the seal.

Other studies have essentially confirmed these findings. A US Army group found no significant difference.
in microleakage when they removed all but 4 mm of laterally condensed gutta-percha and sealer with four different methods of removal: a flame-heated endodontic plugger, an electrically heated Touch 'n Heat spreader, Peeso reamers, and GPX burs. GPX burs (Brasseler; Savannah, Ga.) are designed specifically to remove gutta-percha and will not engage the dentin walls (Figure 11-92). Others have evaluated the efficacy of the methods used in filling canals prior to post preparation. In a Belgian leakage study, researchers found “no significant difference between obturation techniques”: silver points, lateral compaction, warm/vertical compaction, Ultrafil injected, or Obtura technique.

At Loma Linda University, lateral and vertical obturation was followed by gutta-percha removal with hot pluggers down to 5 to 6 mm from the apex. Coronal leakage studies in these specimens were then compared with Thermafil obturation in which the metal-core carrier was notched 5 to 6 mm from the tip and then twisted off after the obturator was fully into place. “The apical plugs in the Thermafil group had the highest degree of coronal dye penetration.” The reason behind a coronal leakage study was based on the fact that cemented posts have an inherently weak seal and that oral fluids (with bacteria) penetrate apically alongside the post and may reach the periapex if the apical gutta-percha plug fails.

Saunders et al. found in apical leakage studies that when Thermafil plastic core carriers were used, the seal was not adversely affected by either immediate or delayed post preparation. Mattison found little difference between Thermafil plastic and metal carriers. A significant Swedish report of periradicular radiolucencies found that 15% of the failure cases had posts in place. The important findings, however, were the relationships to the length of the remaining apical plug and the ineffective cemented seal of the post. A significantly higher percentage of failures was related to apical fillings under 3 mm (Figure 11-93), and 24% of the posts with improper cement seal were associated with periradicular radiolucencies.

REMOVAL OF DEFECTIVE ROOT CANAL FILLINGS AND OBJECTS AND RE-TREATMENT

Endodontists have long complained that their specialty has regressed from primary care into “re-treatodontics.” Many specialists note that 30 to 50% of their practice is re-treatment. That includes having to take over a partially treated case, or worse yet, having to remove defective root canal fillings and entirely redo the treatment.

Chenail and Teplitsky reviewed the iatral as well as patient-placed objects that block root canals. Among the iatral obstructions, they listed paper points, burs, files, glass beads, amalgam, and gold filings (and, one might add, plugger and spreader tips, and of course gutta-percha, cements and sealers, broaches, silver points, and posts). Among the objects placed by patients in teeth left open to drain, they listed nails, pencil lead, toothpicks, tomato seeds, hatpins, needles, pins, and other metal objects. Numerous methods and devices have been developed to retrieve and remove these obstructions.

Gutta-percha and Sealer Removal. Compared with other filling materials, gutta-percha and sealer are

Figure 11-92 Brasseler GPX gutta-percha remover fits low-speed handpiece and features spiraled vents through which gutta-percha extrudes coronally as it is plasticized by frictional heat. (Courtesy of Brasseler, USA, Inc.)

Figure 11-93 Frequency of periradicular lesions related to the length of the remaining gutta-percha root canal filling in 424 endodontically treated roots with posts. Note the much lower failure rate with 3 mm or more remaining filling. Reproduced with permission from Kvist T et al.
relatively easy to remove. After the canal orifice of the defective filling is uncovered, the adhesion of the gutta-percha is tested with a fine Hedstroem file. That is, an attempt is made to pass the file alongside the filling to the apical stop. If the filling is really defective, it may be lifted out by blades of the file, or possibly, with two fine files, one on either side of the gutta-percha.

If the gutta-percha is solid but the filling failed because it is well short of the apex, a hot plugger may be repeatedly plunged into the mass, bringing out gutta-percha each time. As much of the filling as possible should be removed by heat before instruments are used to complete the job. Pieces of filling in the canal have been known to divert the file, and with persistence, a perforation may be developed (Figure 11-94). Peeso reamers, Gates-Glidden drills, and round burs should not be used because they are easily diverted. A GPX gutta-percha remover is less dangerous in a low-speed handpiece because it coronally extrudes the frictionally heated gutta-percha without contacting the dentin walls (see Figure 11-92).

Occasionally, gutta-percha solvents will need to be used. Again, a “well” is made in the center of the defective filling and one or two drops of solvent are introduced from a syringe or the beaks of cotton pliers. The reaming and filing actions are much improved as the gutta-percha dissolves. One must be careful, however, not to pump the liquified mixture out through the apical foramen. Larger files are used high in the canal, decreasing markedly in size toward the apex. After the bulk of the old filling is removed, aggressive filing is done in an attempt to remove all of the gutta-percha and sealer from the walls. Plaques of smear layer, debris, and bacteria must be uncovered to ensure future success.

The solvents commonly used to liquefy gutta-percha are chloroform, xylol, eucalyptol, and halothane. Chloroform has been the favorite but fell into disfavor from a carcinogenic scare. Halothane was recommended as a substitute even though it is harder to obtain. With the lifting of the FDA ban on chloroform, fear of it waned and it is still widely used.

A number of studies evaluated solvents plus mechanical means of filling, namely, removal and reinstrumentation. Chloroform was used successfully in bypassing gutta-percha in well-sealed canals using a Canal Finder System with K-files. The vertical stroke of the Canal Finder handpiece served well to carry the files to the apical stop in an average of 32 seconds in the in vivo cases.

Wilcox et al. found that no technique or solvent removed all of the debris, although it appears that initially using heated pluggers, followed by chloroform with ultrasonic instrumentation, had a slight edge. Wilcox later found canals were no cleaner when either chloroform or sodium hypochlorite was used.

Others have compared chloroform with other solvents, and each time chloroform comes out ahead as the most rapid and complete solvent. Chloroform dissolves gutta-percha nearly three times faster than halothane. A US Navy group found “halothane to be an acceptable alternative to chloroform,” particularly when used with ultrasonic instrumentation. At Creighton University, a group found both chloroform and halothane effective in removing Thermafil gutta-percha fillings with plastic cone carriers.

Re-treatment Success Following Gutta-percha and Sealer Removal. Bergenholtz et al. examined 660 teeth after re-treatment for failures and reported a 94% success rate 2 years later. Of the cohort with periapical radiolucencies, however, 48% completely healed, 30% appeared to be healing, and 22% remained as failures. They later reported that, when teeth with periapical lesions had overextensions during retreatment, success was significantly reduced.

![Figure 11-94 Perforation (arrow) developed during attempt to remove old gutta-percha filling. Small pieces of gutta-percha will divert endodontic instruments leading to perforation.](image-url)
Block and Langeland reported re-treatment of 50 endodontic failures that had been filled with N2. They too stated that “...paste placed beyond the foramen caused tissue damage and reduced prognosis.”

**Hard Paste Filling Removal.** Gutta-percha and soft sealer removal is one thing, but removing hard pastes and cements such as N2, zinc phosphates, and silicates, that have no known solvents, is quite another. Krell and Neo reported the successful yet laborious removal of hard pastes using a Cavi-Endo ultrasonic unit.534 At the University of Minnesota, using an Enac ultrasonic device with continuous water irrigation and a No. 30 file, they were able to remove hard paste fillings in 3 minutes in one case and 10 minutes in another. The Enac unit vibrates at 30,000 Hz and had to be operated at the full setting of “8” to be effective. The Cavi-Endo vibrates at 25,000 Hz.535

**Silver Point, Post, and Obstruction Removal.** The removal of a cemented silver point is usually more difficult than the removal of gutta-percha. If the point is broken off down in the canal, a method suggested by Feldman536 in 1914 and modified by Glick (D. Glick, personal communication, February, 1965) may be used. Glick forces three fine Hedstroem files down alongside the point as far as they will go (Figure 11-95, A). The three files are then twisted around one another, thus entangling the soft silver point in a grip much like that exerted by a broach holder (Figure 11-95, B). This method has also been compared with the grip exerted by the trick Mexican straw “finger-cot” that becomes tighter the harder one pulls. The gradual pull on the files often loosens the silver point. This procedure may be repeated a number of times, each time loosening the silver point a bit more.

Getting down alongside the point to get a purchase with the files may be difficult. Using a No. 1/2 round bur in a slow handpiece, removing sealer and dentin but not nicking the point, is a start. After this, small files, chloroform, and/or EDTA may extend the distance alongside the point to allow deeper penetration with the very fine Hedstroem files.

If the point has fortunately been left protruding into the pulp chamber, a sharp spoon excavator or curette also may be used to pry the point from its seat. A more efficient spoon excavator has been marketed by Stardent with a triangular notch cut out in the tip of the blade. With this modification, the blade grips the silver from two sides rather than just by the curve of the blade, (Figure 11-95, C). Silver points may sometimes be grasped with an alligator ear forceps or an ophthalmic suture holder (Castroviejo curved) (Hu-Friedy; Chicago, Ill.), broken loose from the cement by twisting, and removed.

Rowe has devised another technique using cyanoacrylate glue (Permabond or Superglue #3) and hypodermic needles (A. H. R. Rowe, personal communication, 1981). From an assortment of different gauge needles, one is selected that fits snugly, like a sleeve, over the protruding silver point. The bevel is removed, blunting the needle, which is then cemented over the silver point. After 5 minutes of setting time, the needle is grasped with pliers or heavy hemostat and the silver point “worried” from place (Figure 11-95, D). A variation of this method uses a larger-gauge needle and a small Hedstroem file. The piece of blunted needle is placed over the butt of the silver point. The file is then inserted down the inside of the needle and wedged tightly into the space between (Figure 11-95, E).

Another unique approach uses orthodontic ligature wire and plastic tubing. First, a groove is cut around the protruding butt end of the silver point with a half round or wheel bur. The ligature wire is then doubled over, and the two free ends are passed through the tubing to form a loop at the end. The groove in the silver point is then “lassoed” with the wire loop (Figure 11-95, F), which is cinched up tight with the plastic sleeve. Adding a drop of cyanoacrylate cement may improve the grip. The tubing is tightly grasped with pliers or a hemostat and the point is worked loose.537

Acknowledging the source (see Figure 11-95, D), Johnson and Beatty developed a commercial version of this tube/cyanoacrylate device. It may be used to remove silver points, broken files, cemented posts, or metal carriers of Thermafil.538 The EndoExtractor (Brasseler, USA) consists of tubular, trepan-end cutting burs described by Masseram,539 along with a variety of sizes of tubes with handles attached. The different-sized trepan burs fit over the point/post and are used to cut a trench around it, thus freeing a few millimeters of the point that may be grasped. An appropriate-sized hollow-tube extractor is chosen that will snugly fit the extruding point. The extractor is then cemented to at least 2 mm of the point with cyanoacrylate glue, and 5 minutes are allowed for it to set. The handle on the tube may then be used to twist and lift the point from its seat. At the University of Minnesota, researchers have reported the successful use of the EndoExtractor to remove posts, silver points, and broken files when all else failed.540

An improved version of the EndoExtractor (Roydent Dent. Prod., USA) uses the same principle, except that a “Jacobs chuck,” activated by a twist of the handle, grasps the point/post, so that it may be pulled from the canal. Ruddle has also developed a post puller, the Ruddle Instrument Removal System (IRS)
Figure 11-95  Methods of removing silver points. A, Three fine Hedstroem files are worked down alongside silver point. B, By clockwise motion, three files are twisted around each other, forming vise-like grip on soft silver that can then be dislodged. C, Special “split-tongue” excavator used to pry point from place. D, Blunted hypodermic needle that fits tightly over silver point attached by cyanoacrylate. When adhesive sets, needle is grasped with pliers or heavy hemostat. E, Loose-fitting blunted hypodermic needle is placed over silver point. Hedstroem file is wedged alongside and used to “worry” point loose. F, Loop of orthodontic wire in plastic sleeve used to “lasso” groove cut in silver point. Cyanoacrylate may be used to improve attachment.
(Dentsply/Tulsa Dental; Tulsa, Okla.), that trephines around the post by ultrasonics, then screws onto it and levers the post from the canal.

Ultrasonic/Sonic Removal of Canal Obstructions. “The tightly fitted, well-cemented silver point that is flush with the canal orifice is a challenge to remove.” In these cases, and in the case of cemented posts, removal is enhanced through the use of sonic or ultrasonic devices. At the University of Iowa, researchers placed a fine Hedstroem file down into the canal alongside the defective silver point. The file was then enervated by a Cavitron scaler and slowly withdrawn (Figure 11-96). A number of tries were usually necessary before the silver point loosened and could be retrieved.

At UCLA, Kuttler activated posts with a Cavitron scaler until the cement seal was broken and the post could be either extracted or unscrewed.

Deeper in the canal, the ultrasonic CaviEndo endodontic unit, mounted with a No. 15 file, can be used to loosen obstructions and often “float” them out. At the University of Saskatchewan, it was reported that copious water irrigation was necessary and that “gentle up and down strokes were used until the fragments floated out…” They removed not only silver points and broken files, but spreader and bur tips as well. They warn that patience is needed.

In Germany, the use of the Canal Finder System vertical stroke handpiece retrieved 50% of the defective silver points and fractured instruments. Alternate use of an ultrasonic activated file was also recommended.

One must conclude that the ultrasonic and sonic handpieces have added a whole new dimension to clearing obstructed canals, whether soft gutta-percha and sealer, hard setting cements, or metallic objects that must be removed for re-treatment.

TEMPORARY CORONAL FILLING MATERIALS

An unusual amount of research time and effort has been expended in testing the efficacy of various intermediate coronal filling materials. At the outset, it is safe to say that neither gutta-percha nor temporary stopping is presently used. Since those days, quickly placed, yet apparently adequate, cements such as Cavit (Premier Dental, King of Prussia, Pa.) have dominated the field.

To properly select a temporary, one should know the criteria for selection. “The role of these cements is to prevent the root canal system from becoming contaminated during treatment by food debris, buccal fluids and microorganisms.” Torabinejad et al. have pointed out that, during or after treatment, root canals can be contaminated under several circumstances: (1) if the temporary seal has broken down, (2) if the filling materials and/or tooth structure have fractured or been lost, and (3) if the patient delays final restoration too long.

The properties that a good temporary material must possess have been well delineated by French researchers: good sealing to tooth structure against marginal microleakage, lack of porosity, dimensional variations to hot and cold close to the tooth itself, good abrasion and compression resistance, ease of insertion and removal, compatibility with intracanal medications, and good esthetic appearance.

This same French group has produced the definitive study on the leading temporary cements presently on the market: Cavit and IRM and TERM (Dentsply/Caulk, USA). They note that Cavit is a premixed paste supplied in collapsible tubes, that IRM is a ZOE cement reinforced by a polymethylemethacrylate resin, and that TERM is a light-cure composite (urethane dimethacrylate polymer resin).

Others have learned that Cavit can cause discomfort in vital teeth, probably through dessication. Also, it is a moisture-initiated, autopolymerizing premixed calcium sulfate polyvinyl chloride acetate cement, and it expands while setting. IRM must be mixed on a slab, and thus porosity may be incorporated; TERM is injected into the cavity and light cured for 40 seconds.

French researchers used bacteria in their microleakage study because bacteria are the principal problem. Streptococcus sanguis, an oral pathogen, is 500 times greater in size than blue aniline dye. Therefore, any
leakage indicates “wide” gaps or high porosity. The French group placed temporary fillings 4 mm thick and tested leakage after 4 days of immersion in bacteria, and then after thermocycling from 4 to 57°C.

They found that Cavit and TERM did not allow bacteria to penetrate before or after thermocycling, whereas 30% of the IRM fillings let S. sanguis pass before thermocycling and 60% of the IRMs leaked after thermocycling. They believe that IRM was leaking through the filling material itself because of mixing porosity, as well as marginally.\textsuperscript{543} There is no question that, for short-duration, intermediate fillings, Cavit and TERM are preferred.

Seven years later, the French group again tested the efficacy of Cavit, IRM, TERM, and a new adhesive, Fermit (Vivadent, France/USA), via leakage studies.\textsuperscript{546} They concluded that “Cavit was more leakproof than the other cements at day 2...and at day 7.” Cement thickness averaged 4.1 mm.\textsuperscript{546}

In Taiwan, a new temporary material, Caviton (G-C Dental, Japan/USA), was tested against Cavit and IRM. The Chinese reported that Caviton provided the best seal, followed by Cavit. IRM was a poor last.\textsuperscript{547}

Others have tested these materials (Cavit, IRM, and TERM) and other temporary cements as well. The results are confusing, probably because of the indicator dyes used, the significant temperature changes,\textsuperscript{548–550} the softening effect of medicaments,\textsuperscript{552,553} and the length of time the fillings withstand the variables.\textsuperscript{554}

Some found that Cavit must be at least 3.5 mm thick,\textsuperscript{554} and that one should not plan an “intervisit period for longer than 1 week.”\textsuperscript{553,555} Most found Cavit, Cavit-G, and Cavit-W (hardness variations) as good as, if not the best of, the temporaries.\textsuperscript{543,555–563,567} Others found Cavit less adequate than IRM and ZOE cements.\textsuperscript{550,551,564,568–570}

Many studies agreed with the Deveaux group in Lille, France, that TERM was superior or equal to all of the other temporary coronal sealants.\textsuperscript{543,558,561–564,571} At the Universities of Iowa, Saskatchewan, and California, workers disagreed with the value of TERM as a sealant.\textsuperscript{556,559,560} Most others also agreed with Deveaux that the use of IRM is ill-advised, and that it leaks badly before and after thermocycling.\textsuperscript{543,558,559,562–564}

More recently, a Berlin group found it efficacious to add glass ionomer cement to temporary replacements.\textsuperscript{572} They reported that “only glass-ionomer cement and IRM combined with glass-ionomer cement may prevent bacterial penetration to the periapex of root filled teeth over a 1 month period.”\textsuperscript{572}

Some research groups found zinc phosphate and polycarboxylate cements most inadequate,\textsuperscript{562,563} but the glass ionomer Ketac Fil to be quite adequate if the cavity is first acid etched. This rather time-consuming approach gave a similar result to Kalzinol (Dentsply/DeTrey, Switzerland/USA), a reinforced ZOE cement.\textsuperscript{555}

There are other factors that might affect the temporary seal, one being the intracanal medicaments that could dissolve and loosen the seal from below. Rutledge and Montgomery found, however, that neither eugenol, formocresol, nor CMCP broke the seal of TERM, although the “walking bleach” paste of sodium perborate and superoxol did so.\textsuperscript{573} Another group suggested that a pellet of cotton soaked in a medicament (CMCP) would act as a barrier if bacteria leaked through the temporary filling.\textsuperscript{574}

Does a filling already in place that is penetrated by the access cavity have any effect on microleakage? The answer is yes on two counts. First, the filling itself may be faulty and leaking, and second, the temporary filling-in-the-filling may not adhere, and leakage will ensue.

If one suspects that the filling to be perforated for access is already faulty, it should be totally removed.\textsuperscript{560} If this happens, a temporary filling will have to withstand the trauma and abuse suffered by a two- or three-surface filling. In this event, a temporary material must be chosen to withstand these stresses. At the University of Georgia, researchers determined that “TERM restorations provided excellent seals and were statistically superior to Cavit and IRM for restoring complex endodontic access preparations.” IRM leaked immediately from “thermal stress.” Cavit has a setting expansion of 14%, so that it literally “grew” right out of Class II cavities and severely cracked. Its low compressive strength and high solubility made it unacceptable for long-term use.\textsuperscript{564}

At the University of Georgia, workers prepared endodontic access cavities in Class I amalgam fillings and then restored the access cavities with various temporary materials. Glass ionomer, TERM, Cavit-G, and IRM “all provided excellent seals” for up to 2 weeks, whereas zinc phosphate and polycarboxylate cements proved inadequate. No thermocycling was done. It tends to break the seal of all of these materials placed in amalgam cavities.\textsuperscript{565}

At Indiana University, they tested ZOE and Cavit in cavities prepared in amalgam and composite. They found that “ZOE seals against marginal leakage better than Cavit when the access opening is placed through composite resin, and that Cavit seals better than ZOE when the access opening is placed through amalgam.” Thermocycling apparently broke the bond with amalgam.\textsuperscript{566}

Torabinejad et al. pointed out the importance of the temporary seal lasting even after root canal therapy is
completed, emphasizing the importance of early final restoration of the tooth. It took only 19 days for Staphylococcus placed in the crown to reach the apex in 50% of the test cases and 42 days for 50% of the Proteus samples to do the same.© The Torabinejad team later reported that bacteria in natural saliva will contaminate root canals obturated by either lateral or vertical compaction, from crown to apex, in just 30 days if left open to the saliva.©

At Temple University, it was found that bacterial endotoxin could penetrate the full length of an obturated canal in just 20 days.© More recently, the Iowa group found that endotoxin, "a potent inflammatory agent, may be able to penetrate obturating materials faster than bacteria."© They also extended the caveat: "the need for an immediate and proper coronal restoration after root canal treatment is therefore reinforced."©

One must conclude from this full discussion that temporary fillings are most important in multiple-appointment treatment to prevent recontamination between appointments and, further, that the material must be tough enough to withstand mastication. Between-appointment intervals should not exceed 1 week, and the temporary bases must be thick enough to prevent leakage. Finally, long-term temporization is inadvisable.

TERM and glass-ionomer cement appear to be the most acceptable temporaries, followed by Cavit in Class I cavities. ZOE, zinc phosphate, polycarboxylate cements, and IRM, per se, are much less acceptable, and, of course, temporary stopping is totally unacceptable.

FINAL CORONAL RESTORATION: MICROLEAKAGE

It might be that as many root canal fillings fail because of bacterial entry from leaking coronal restorations as fail from periradicular leakage. As stated earlier, Torabinejad et al. demonstrated an inordinate (50%) bacterial contamination from the crown clear through to the apex, around and through well-compacted gutta-percha fillings.©

After bacteria pass permanent occlusal fillings, there appears to be a clear track right past the bases placed over the root canal filling—either zinc phosphate cement or temporary stopping.©

Melton et al. recommended that leaking permanent restorations "should be removed in their entirety before endodontic treatment"©; it makes even more sense to remove any suspicious restorations after treatment as well, not try simply to restore the access cavity.

There is a terrifying body of literature, for example, that testifies to microleakage all the way to the pulp under full crowns.©–© One must assume that, along these pathways, bacteria could reach the pulp space occupied by root canal fillings and then down the root canal filling to the apex.© "None of the current luting agents routinely prevent marginal leakage of cast restorations."© Furthermore, "...all crowns leaked gingivally regardless of the type of crown margin preparation."©

Therefore, it goes without saying that so-called “permanent” restorations of endodontic access cavities suffer microleakage as well. At the University of Iowa, Wilcox and Diaz-Arnold restored lingual access cavities with either Ketac-Fil glass ionomer cement or Hercule composite resin (Sybron Endo/Kerr Dental Orange, Calif.). Acid etch was used as well as GLUMA dentin-bonding agent. After thermocycling, all of the specimens leaked and they leaked right past the zinc phosphate and/or temporary-stopping bases underneath. One specimen even leaked all the way to the apical foramen.©

A series of experiments at the University of Iowa found that coronal microleakage, in the presence of saliva, was inevitable up to 85% of the time.© At Indiana University, researchers also noted the penetrating effect of saliva and recommended "re-treatment of obturated root canals that have been exposed to the oral cavity for at least 3 months."©

To confirm in vivo the penetrating effects of saliva from leaking coronal restorations seen in vitro, the Iowa group did coronal microleakage studies on monkeys. They reported dye penetration down the filled root canals no matter which sealer was used: Sealapex, AH-26, or ZOE.©

Undoubtedly, one of the causes of microleakage under cemented restorations relates to the dissolution of the cement. Phillips et al., in a human in vivo study, found that zinc phosphate cement was much more likely to disintegrate than were polycarboxylate or glass ionomer cements.© This is particularly important because zinc phosphate is still the most widely used luting agent.

If all of these standard luting cements are faulty in their sealing ability, what is one to do to prevent microleakage? The answer appears to lie in the use of the new adhesive resins, or glue that will adhere to all tooth structures, as well as metals, other resins, and porcelain.

Tjan, Tan, and Li, at Loma Linda University, have shown that when the 4-META adhesive Amalgambond (Parkell Dental, Farmingdale, N.Y.) is used to line both the prepared dentin and enamel, the newly placed amalgam filling is virtually leakproof (Figure 11-97, A).
In contrast, a cavity lined with Copalite allowed leakage around the amalgam as far as the pulp\(^ {589,590}\) (Figure 11-97, B). Amalgambond can also be used to bond new amalgam to old amalgam, or composite to amalgam, gold, or other composite. Another 4-META product, C & B Metabond (Parkell Dental, USA), will lute gold or porcelain restorations to tooth without future leakage.

Wilcox attempted to use GLUMA (Miles Laboratories, USA), the dentin-bonding agent, to adhere a composite resin to the tooth structure of endodontic access cavities in anterior teeth. After thermocycling, it failed.\(^ {578}\)

At this juncture, the solution to the problem of microleakage appears to be the resin-adhesive agents, particularly those that will adhere to more than just other resins, and possibly another approach—placing an intraorifice barrier base, medicated or nonmedicated, over the coronal root canal filling.

At the University of Tennessee, the Himel group placed pigmented glass-ionomer cements over the coronal termination of the root canal filling. They reported that “the teeth without an intraorifice barrier leaked significantly more than the teeth with the [glass-ionomer] barriers (\(p < .05\)).”\(^ {591}\) Similar research at Northwestern University revealed much the same results—the root canals that received an intraorifice barrier leaked significantly less than the unsealed controls, all of which leaked in < 49 days.\(^ {592}\)

At the University of Toronto a different approach was tried—sealing the canals with two experimental glass-ionomer sealers, one containing an antimicrobial substance. The first sealer proved effective in preventing the “penetration of \(E.\ faecalis\)” probably because of the natural release of fluoride. The experimental sealer with the added antibacterial “needs more study.”\(^ {593}\)

Martin has recently introduced gutta-perch points and an accompanying ZOE sealer, both of which contain iodoform, a well-known bacterial suppressant. In vitro results appear promising; however, long-term in vivo efficacy has yet to be shown. The products are marketed as MPG gutta-percha points and MCS root canal sealer (Medidenta Products, Woodside, N.Y.).

**A NEW ENDODONTIC PARADIGM**

It has been recognized for decades that the ideal end result of root canal therapy would be the closure of the apical and all lateral foramina with reparative cementum.\(^ {594,595}\) This permits re-establishment of a complete

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**Figure 11-97** Comparative study in microleakage between resin adhesive and copal varnish. A, Amalgam filling bonded to dentin (D) and cementum (arrow) with Amalgambond and no microleakage. B, Amalgam filling lined with Copalite. Gross microleakage at gingival floor (arrows) as well as from upper margin (curved arrow). (Courtesy of Drs. A. H. L. Tjan and D. E. Tan.)
attachment apparatus and precludes future failure caused by pulpoperidontal fluid exchange and retroinvasion of bacteria.

Following well-executed treatment, wherein infection and irritation are terminated, cementoblasts and periodontal ligament slowly resurface the damaged root and even close minor foramina that no longer contain neurovascular bundles.

But well-obturated major foramina that present a surface of sealers and/or gutta-percha to the periradicular tissue will not be closed over. Cementum will not grow across mildly irritating sealer surfaces. This leaves these foramina vulnerable to leakage as cement sealers dissolve away over the years. How can this dilemma be resolved?

Cementification. In the last two editions of this text, Ingle and Luebke made a case for the wider use of calcium hydroxide as a stimulating and healing agent (Figure 11-98). The same thought occurred to others—to use calcium hydroxide in filling the canal as well as an interappointment canal medicament. In other words, these sealers must dissolve to release their calcium hydroxide. It then becomes a question of which will happen first—cementification across the apex or leakage into the exposed canal with its attendant problems? Is there a substitute for calcium hydroxide that may have its stimulating effects but not its drawbacks? The answer may be hydroxyapatite!

Calcium-Phosphate Cement Obturation. Years ago, Nevins and his associates were using cross-linked collagen–calcium phosphate gels to induce hard tissue formation. More recently, Harbert has suggested using tricalcium phosphate as an apical plug, much like dentin shavings and calcium hydroxide have been used. Even more recently, calcium phosphate cement (CPC) has been suggested as a total root canal filling material. The ADA-Paffenbarger Dental Research Center at the US National Institute of Standards and Technology has developed a simple mixture of calcium phosphates that sets to become hydroxyapatite. “Two calcium phosphate compounds, one acidic and one basic, are unique in that when mixed with water they set into a hardened mass”—hydroxyapatite—the principal mineral in teeth and bones. Tetracalcium phosphate is the basic constituent, and the acidic component is either dicalcium phosphate dihydrate or anhydrous dicalcium phosphate. “Water is neither a reactant nor an important product in the reaction, but merely a vehicle for dissolution of the reactants.” Setting time may be extended by adding glycerin to the mixture. Using a mild phosphoric acid solution speeds the dissolution of the components. Even aliquots of blood from a surgical site may be substituted for water.

The final set, calcium phosphate cement (CPC), consists of nearly all crystalline material, and porosity is in direct ratio to the amount of solvent (water) used. It is as radiopaque as bone. It is nearly insoluble in water and is insoluble in saliva and blood, but is readily soluble in strong acids, which may be considered in the event it must be removed.

In testing the sealing ability of CPC when used as a root canal sealer-filler, the Paffenbarger group reported that the “…disintegration of Sealapex indicated that solubility may be the price for increased activity.” In other words, these sealers must dissolve to release their calcium hydroxide. It then becomes a question of which will happen first—cementification across the apex or leakage into the exposed canal with its attendant problems? Is there a substitute for calcium hydroxide that may have its stimulating effects but not its drawbacks? The answer may be hydroxyapatite!

Obturation of the Radicular Space

Figure 11-98 Calcification forming around nidus of calcium hydroxide in tissue (arrow). (Courtesy of Dr. Raymond G. Luebke.)
CPC is concerned, the “calcium phosphate treated animals showed mild irritation after 1 month, but thereafter the adverse tissue reactions were minimal. New bone formation adjacent to the cement was also observed.” In another study, 63% of the specimens showed no evidence of inflammatory response to the CPC. Still another study, done on monkeys, in which canals were deliberately overfilled, new bone formation developed immediately adjacent to the cement (Figures 11-100, 11-101). Exhaustive tests of CPC by Chinese researchers in Shanghai found that “CPC had no toxicity and all tests for mutagenicity and potential carcinogenicity of CPC extracts are negative.” They also noted that “the implant tightly joined with the surrounding bone...”

Krell and Wefel also found that, as a sealer, CPC adheres well to the canal wall. In marked contrast to


Figure 11-100 Periradicular area 3 months after purposeful overfill of canal with calcium phosphate cement CPC. The CPC (C) is bordered by slender new bone trabeculae (NB) at the periphery where foam histocytes (H) are frequently present (right). LB, lamellar bone. A, ×75 original magnification. B, ×300 original magnification. Reproduced with permission from Hong YC et al. 218
CPC, leakage was observed in the gutta-percha/ZOE controls (see Figure 11-99). And at the US Naval Dental School, CPC was used as an apical barrier to facilitate obturation much as dentin chips and calcium hydroxide have been used. “The teeth receiving apical CPC barriers...had significantly less dye penetration than teeth without apical barriers.” They recommended CPC as a replacement for calcium hydroxide in apexification cases.

Japanese researchers have already marketed apatite sealers. Two of them, G-5 and G-6, were tested at Indiana University against Super-EBA for biocompatibility. While finding Super-EBA and G-5 biocompatible, the researchers found G-6 “promoted moderate inflammation and foreign body giant cell response.” In addition to CPC, both G-5 and G-6 contain radiopacifiers, potassium fluoride, and citric acid, except G-6 contained more of the latter.

A Japanese group at Osaka tested another commercial apatite sealer, ARS (Apatite Root Sealer), and found that it “caused severe inflammatory reactions.” In the same test, the Osaka group added 2.5% chondroitin sulfate to CP cement (TMD-5) and reported that it “has excellent histocompatibility and potential as a root canal sealer.”

An Italian company has added hydroxyapatite to ZOE sealer, Bioseal (Ogna Lab. Farma., Italy), much as calcium hydroxide has been added to CRCS sealer. Whereas Gambarini and Tagger reported that Bioseal “did not adversely affect the sealing properties” of the cement, its beneficial effects were “not within the scope of the study.”

In an entirely different direction in the development of apical barrier materials, Japanese researchers have tested the use of freeze-dried allogenic dentin powder as well as True Bone Ceramics (TBC), the latter derived from the incineration of bovine bone. Initially, with both products, multinucleate giant cells and bone resorption appeared. Within 3 months, however, new bone had formed and “the apex had been closed completely with new hard tissue.”

If a delivery system can be perfected for CPC, it could well be the sealer/barrier/filler of future endodontics. The Paffenbarger Center did find that their material provided better sealant qualities than did ZOE and gutta-percha. The fact that hydroxyapatite is a naturally occurring product, and that bone grows into and eventually replaces extruded material, makes it very acceptable biologically. Moreover, it may replace calcium hydroxide in treating open-apex cases and fractured roots.

Another possibility of using hydroxyapatite relates to the laser. A cross-linked collagen-hydroxyapatite mixture has been placed in the root canal and “melted” to place with a laser beam through a fiber optic.

To date, none of these uses of calcium phosphate cements have been approved by the US Food and Drug Administration, although clinical trials have been applied for. This long, slow, and costly process must be undertaken before the products can be released for use by the profession. More recently, an experimental material, mineral trioxide aggregate (MTA), has been suggested as a root-end filling material. This may also turn out to be a promising material for use as an orthograde filling of the apical end of the root canal prior to filling the remainder of the canal with gutta-percha. It is presently being used primarily as a retrofiling material.

Adhesive Resins. Very little has been published on the use of adhesives in filling root canals.
stands to reason that adhesive resins could serve to seal dentin walls after smear removal. If it can be made to adhere to other filling materials such as gutta-percha, and if it can be made radiopaque without ruining its setting and adhesive qualities, one would think that adhesives may have a bright future in endodontics. **Amalgambond** already has been used to seal amalgam retrofit fillings against microleakage.

At the University of Minnesota, Zidan and El Deeb found that **Scotchbond**, which bonds chemically to calcium, provided a significantly better seal than Tubliseal.130,131 In Australia, Gee found that he could only achieve a result comparable to lateral compaction with AH-26 as a sealer by falling back on a complex system involving GLUMA as a bonding agent, followed by Concise composite, plus AH-26 and gutta-percha. GLUMA and Concise alone gave a poor leakage result.614 This hardly speaks well for GLUMA or Concise.

Kanca has shown that certain “bonding” agents will not adhere to moist dentin. GLUMA is one of these, as well as Scotchbnd II, Clearfill, Photobond, and Tenure. Since it is almost impossible to totally dry a root canal, an adhesive must be selected that bonds to both wet and dry dentin. Kanca recommended **All Bond 2** (Bisco Dental, USA),615 although Amalgambond and C & B Metabond are just as effective.

**SUMMARY**

All in all, one must be aware that on the horizon, there are a number of possible methods of obturating root canals that will be “kinder and gentler.” More laboratory and clinical research is needed, along with FDA approval, before a new endodontic paradigm is fulfilled. Endodontics is moving from nineteenth-century gutta-percha and calcium hydroxide into the twenty-first century of chemistry and lasers. The transition is slow, but exciting.

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