Methods of filling root canals: principles and practices

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Contemporary research points to infection control as the key determinant of endodontic success. While epidemiological surveys indicate that success is most likely in teeth which have been densely root-filled to within 2 mm of root-end, it is unclear whether the root canal filling itself is a key determinant of outcome. It is also unclear how different materials and methods employed in achieving a ‘satisfactory’ root filling may impact on outcome. This article provides an overview of current principles and practices in root canal filling and strives to untangle the limited and often contradictory research of relevance to clinical practice and performance.

Introduction

Successful root canal treatment depends critically on controlling pulp-space infection. In evaluating root canal-treated teeth, it is unusual for external assessors to have full information on the methods used and the detail of infection-controlling steps. Attention therefore tends to focus on aspects of treatment which can be readily identified and measured, such as the radiographic nature, length and density of root fillings, with the assumption that these are good proxy markers of the overall package of infection-managing care. It is not surprising that the majority of epidemiological surveys in endodontics have focused on radiographic appearances alone (1), despite our recognized limitations in radiographic interpretation (2, 3), and acceptance that the radiographic ‘white lines’ reveal only limited information.

The classic ‘Washington study’ (4), although never published in a peer-reviewed journal, set the tone by observing that 58.66% of endodontic failures were caused by incomplete obturation. Other well-established undergraduate textbooks have emphasized that ‘lack of adequate seal is the principal cause of endodontic failure’ (5), positions based on the best clinical scientific evidence at the time.

Contemporary research points to cleaning and shaping of the root canal as the single most important factor in preventing and treating endodontic diseases (6), and it is difficult to endow root canal filling with the same primary importance. But to take such views too rigidly, and to use reports of periapical healing without definitive root filling as evidence that root canal filling is unnecessary (7–10) is to miss the important role it may play in securing short- and long-term health (11, 12).

In technical terms, we anticipate that ‘success’ will be associated with root canals (prepared and) densely filled to within 2 mm of radiographic root end (1, 13). However, the body of high-quality clinical research on which such conclusions are founded is limited (14). Even less clear is whether a technically ‘satisfactory’ root canal treatment will deliver health regardless of the materials and methods, or whether some are inherently ‘better’ than others in terms of predictability, safety, consistency, healing, and tooth longevity.

Commercial pressures and glossy advertising have never been more prominent, but the debates are not new. As early as 1973, Brayton et al. (15) noted that ‘Many techniques have been advocated for filling root canals. Controversies and disputes have arisen, dividing practitioners into different schools of thought. To date, there is still very little evidence other than clinical impression to support or deny any particular technique.’

As no single approach can unequivocally boast superior evidence of healing success (13), decisions may be based on such factors as speed, simplicity, economics, or ‘how it feels in my hands.’ For some, there may be other issues at stake, such as the desire to keep ‘up to date,’ to demonstrate ‘mastery,’ to keep ahead of referring
colleagues, or to enliven the working day by ‘the thrill of the fill’ (16) as unexpected canal ramifications are demonstrated more consistently. For others, issues such as root strengthening, or a fundamental lack of confidence in established materials may be critical (17–19).

The role of root canal fillings in endodontic success

The shaped and cleaned canal space represents an environment in which microbial communities have been eliminated or seriously disrupted and can no longer promote periradicular disease (6, 20).

But how is this condition preserved? Undue reliance on a coronal seal is probably unacceptable without first filling the canal system (21–23) with materials that control infection:

1. Directly: by actively killing microorganisms (24) which remain (25) or which gain later entry to the pulp space, and
2. Ecologically: by denying nutrition, space to multiply, and correct Redox conditions for the establishment of significant biomass of individual microbes, or the development of harmful climax communities.

They should do so long-term and without damaging host tissues.

Basic approaches

Textbook accounts describe a spectrum of filling methods (Fig. 1) ranging from paste-only fills, through pastes with single cones of rigid or semi-rigid material, to cold compaction of core material and finally, warm compaction of core material with sealer paste. It is likely that most accounts have assumed the materials involved to be traditional sealer cements (such as zinc oxide-eugenol pastes) in combination with metallic or gutta percha cones. Sealer cements are usually regarded as the critical, seal-forming ‘gasket’ of the root canal filling (26), but paradoxically, as the weak link of the system whose volume should be minimized by core compaction (27, 28).

Paste-only root fillings

Paste-only root fillings have a poor reputation in clinical endodontics. Notable approaches have included highly toxic resin cements such as ‘Traitement SPAD’ and the original, formaldehyde-containing Endomethasone (Septodont, St Maur des Fosses, France), which were advocated for rapid results in minimally prepared canals. Although success was reported, in some cases after deliberate apical extrusion with a spiral paste-filler (29), such ‘quick and dirty’ approaches appeared to deny the biological perspective that what came out of the canal was more important to success than what went in. Inadvertent accidents of over extension into vital structures such as the inferior alveolar canal left a distressing legacy for affected patients. Concerns were compounded by the all too frequent insolubility and hardness of such materials, making removal for re-treatment a challenge to the most skilled of operators (30, 31).

Even with fluid materials which are regarded as bland and biocompatible, risks of erratic length control...
during application are recognized. Fannibunda et al. (32) reported a case of inferior alveolar nerve paraesthesia, which followed the inadvertent extrusion of molten gutta percha. Porosities in large volumes of fluid paste, setting contraction with loss of wall contact, and dissolution with time have all reinforced the negative views of such approaches. Even 1% shrinkage of a material after setting has been recognized as a potentially significant problem in terms of seal and success (33).

**Single-cone obturations**

For similar reasons, the sealer-heavy root fillings associated with single-cone root fillings have not been regarded well. Single-cone obturations came to the fore in the 1960s with the development of ISO standardization for endodontic instruments and filling points (34). After reaming a circular, stop preparation in the apical 2 mm of the canal, a single gutta percha, silver, sectional silver or titanium point was selected to fit with ‘tug-back’ to demonstrate inlay-like snugness of fit. The cone was then cemented in place with a (theoretically) thin and uniform layer of traditional sealer, at least in the apical part of the canal. Hommez et al. (35) have recently reported that single-cone obturation was still the method of choice for 16% of Flemish dentists. Data from the UK has indicated that 49% of dentists qualified more than 20 years and 13.2% of those qualified 3 years regularly used single-cone techniques (36). All experienced dentists have witnessed success following the use of such techniques in skilled hands, and within the context of infection control. In a retrospective clinical study, Smith et al. (37) demonstrated 84% success following cementation of an apical silver cone with sealer, and 81% with a full-length silver cone and sealer. Equally, all those who accept endodontic referrals are very familiar with single-cone removal from canals in which a large volume of surrounding sealer has leached away or dissolved under the action of tissue or oral fluids. Concerns were compounded by the realization that canal transportation is common and that damaged roots are difficult to seal (38).

The advent of nickel titanium makes predictably centred preparations more realistic than ever in curved canals (39), and may make accurate apical cone fit a possibility in many cases (40). Contemporary advertising on ergonomic, matched file and cone systems may serve to promote single-cone cementation techniques (Fig. 2). Laboratory evidence in fact suggests comparable cross-sectional area of canal occupied by gutta percha using single-matched taper cones compared with lateral condensation, and in significantly less time (41), but clinical trial data is hitherto unavailable.

**Are our views on paste-heavy fills still valid?**

Mineral Trioxide Aggregate (MTA) (Fig. 3) has challenged the view that paste-only root canal fillings are difficult to control, unacceptably porous, dimen-
sionally unstable and unacceptably soluble (42). Unpublished data (43) indicates that endodontists worldwide have adopted this material as first choice in a range of applications from pulp capping, to the non-surgical management of wide open apices.

A medical-grade Portland building cement (44), MTA is mixed into a stiff paste with sterile water. The consistency and behavior may be adjusted by varying the powder:liquid ratio (45), and premature desiccation is prevented by covering the mixed material with moist gauze (Dentsply/Maillefer instruction guide REF A 0405). Although the composition of the grey and white forms is broadly comparable (44), the white version appears to be less ‘gritty’ and more cohesive.

Material may be carried to the canal:
1. In a narrow, MTA carrier (or ‘apicectomy’ amalgam gun),
2. On the end of a plugger after wiping material into the grooves of a dedicated teflon ‘Lee’ block (46), or after expressing a pellet of material from a gun (47) (Fig. 4).

Material is then compacted with pluggers set to extend 2–3 mm short of working length, often supplemented by ultrasonic (48) or sonic vibration with the intention of improving settlement and adaptation, although the merits of vibration remain contentious (49). Further consolidation can be achieved by tamping the material with the broad end of paper points to wick out excess water which could retard the curing process (Dentsply/Maillefer). ProRoot MTA (Dentsply) is then usually overlaid with moist cotton wool or sponge to ensure a humid environment for the hydration setting reaction (Dentsply/Maillefer). The need for this action has not been established. Setting is checked by re-entry at least 4 h after placement, and ongoing treatment may then proceed. Another commercial version, MTA Angelus (Angelus, Londrina, Brazil) (Fig. 3) is claimed to set within 15 min and may therefore require no overlay or re-entry.

MTA is firmly established as the material of choice for open apices (precisely those where length control is likely to be an issue, Fig. 5) (50), and perforation repairs (51), where there is no risk of wash-out during the lengthy setting period. It is possible that MTA may supersede calcium hydroxide ‘apexification’ procedures in the management of traumatized immature teeth (52). Volumetric change and leakage (53) have not been identified as significant issues.

MTA has not yet found widespread acceptance in curved and relatively narrow canals, probably due to difficult manipulation and concerns about re-treatment. But its adoption in a range of challenging applications suggests that concerns about root canal filling cements are not universal. A question that research must answer is whether other classes of cement can be used safely and effectively in thick section during root canal filling.
Can all cements be viewed like traditional endodontic sealers?

Limited evidence exists that other classes of material may also be suitable for ‘sealer heavy’ or minimal compaction techniques.

Glass ionomer cements

Ketac Endo (3M ESPE, St Paul, MN, USA) was developed as an adhesive, root-reinforcing root canal sealer to be applied in thick section with a single gutta percha cone. Evidence on root reinforcement was equivocal (17, 54, 55) and concerns have been expressed about long-term solubility (56, 57), but one clinical trial which included both single cone and cold laterally condensed root canal fillings provided outcomes comparable to those of other materials and techniques (58).

Silicone rubbers

Addition polyvinylsiloxanes are well established in dentistry as inert, dimensionally stable materials. Formulations with reduced hydrophobicity are now widely available, including two developed specifically for endodontics. RoekoSeal (Roeko, Langenau, Germany) is a white, fluid paste, whereas GuttaFlow (Roeko) appears to be based on RoekoSeal, with the addition of powdered gutta percha. Materials are mixed with automix tips similar to impression materials (RoekoSeal) or by trituration (GuttaFlow) before carriage to the canal on a gutta percha cone, or by passive injection through dedicated plastic cannulae (Fig. 6). Single gutta percha cones matching the apical preparation size are seated to length in the sealer-filled canal, encouraging flow to the apical region and into lateral ramifications.

Laboratory investigations indicate 0.2% setting expansion (33), biocompatibility (59), and acceptable wall coverage (60). A clinical trial comparing silicone sealer with zinc-oxide eugenol in lateral condensation revealed comparable healing outcomes (61), but outcome studies on the single-cone method are not yet available.

The optimal canal preparation and shape of cone to ensure adaptation and carriage to length without extrusion has not been established. Silicone rubbers provide long-term seal in a range of wet environments and sealing root canals may be a valid new application (62).

Urethane methacrylates

EndoRez (Ultradent, South Jordan, UT, USA) is a hydrophilic urethane methacrylate resin capable of good canal wetting and flow into dentinal tubules.

The mixed material is deposited into the canal by passive injection through a narrow, 30 gauge ‘Navitip’ needle (Fig. 7) which is claimed to minimize pressure buildup and over-extension. A single cone is again floated to length to encourage material flow and provide a pathway into the canal for re-entry. The material is reported to have acceptable biocompatibility (59, 63, 64) and to seal as well as other established materials in vitro (65). No clinical data are available on paste-only or single-cone EndoRez root canal fillings, although in combination with cold lateral condensation, it was associated with 91.3% healing at 14–24
months (66), results comparable to other materials. Tay et al. (67) have recently described the use of resin coated gutta percha cones in combination with a dual-curing EndoRez in an effort to enhance bond and seal. Resin tags were demonstrated impregnating canal walls, but interfacial leakage was not prevented.

**Epoxy resins**

Epoxy resins are well established as effective root canal sealers, displaying acceptable biocompatibility (68, 69), insolubility and dimensional stability (70).

AH 26 and AHPlus (Dentsply) are classic examples with proven track records over many years of clinical use (71, 72). *In vitro* tests have demonstrated comparable seal in thin and thick section (65, 73).

AHPlus is specifically advocated with the single-cone Lightspeed SimpliFill technique (Lightspeed Technologies, San Antonio, TX, USA). Following the preparation of an apical stop and parallel, cylindrical preparation in the apical 5 mm of the canal with Lightspeed instruments, a size matched gutta percha (or Resilon) apical tip is selected which fits snugly just short of working length in a moistened canal. After conventional drying of the canal, a light coating of sealer is applied, the apical tip is seated firmly to length, and the handle removed by unscrewing anti-clockwise (Fig. 8A). Carpules with 27 gauge needles which form part of a dedicated injection system are then filled with sealer, and the canal backfilled with cement (Fig. 8B). One or more gutta percha points may be added if desired. A recent *in vitro* leakage study has suggested that backfill with AHPlus alone provided a better seal against coronal leakage than AHPlus compacted with injection-molded gutta percha (74).

EZ-fill (Essential Dental Systems, South Hackensack, NJ, USA) is a similar material, presented like AH26 as a powder and liquid for control of material viscosity. Mixing with a warm spatula decreases the material’s viscosity. Controlled delivery is achieved with an innovative ‘bi-directorial spiral’ paste filler (Fig. 9). The bi-directional spiral controls apical flow of sealer cement by virtue of its blades which drive material apically in the coronal region, and coronally in the apical 2–3 mm. Canals are rapidly filled with sealer before floating a pre-fitted 8% gutta percha cone to length without the need for further vertical or lateral compaction (Fig. 10).

EZ-fill is a rapid method, which appears to demonstrate canal complexities well and *in vitro* studies have shown it to seal as well as other established techniques (75). Review of clinical cases managed in a multi-

![Fig. 8. (A) SimpliFill device seated fully to length with sealer before unscrewing the handle; (B) preparing to backfill by injecting sealer.](image)

![Fig. 9. Innovative bi-directional spiral for controlled sealer placement.](image)

![Fig. 10. EZ-fill/single cone root canal filling. (A) Immediate postoperative radiograph, (B) 6-months follow-up (courtesy Barry Musikant).](image)
surgery practice have indicated favorable clinical outcomes estimated at 94.1% (76, 77), although once again, independent clinical trial data are not yet available.

Non-Instrumentation Technology

The previous section has described the delivery of sealer cements by rotary instruments, injection, or carriage on points of core material. A highly innovative approach is found in non-instrumentation technology (NIT), where the controlled development of a vacuum within the tooth allows fluid sealer to be drawn into the complexities of the canal system (78). This technology has been subjected to one clinical trial in which the radiographic quality of root fillings with AH 26 was comparable to that of conventional techniques (79).

Gutta percha compaction methods

Despite the possibilities described, compaction methods continue to dominate clinical endodontics as practitioners strive to optimize density of the core material and minimize sealer volume. It is not established beyond question whether compaction methods benefit patients or dentists by preserving health better, healing more disease or demonstrating more canal complexities. Conversely, they could offer no improvement and risk adverse events such as root fracture or more frequent overfill. One in vitro study has indicated that compaction may reduce canal wall contact and seal of materials with insufficiently low minimum film thickness (26).

Cold lateral condensation

Cold lateral condensation is probably the most commonly taught and practiced filling technique worldwide (35, 36, 80–82) and is regarded as the benchmark against which others must be evaluated. The method is generic, encompassing a range of approaches in terms of master cone design and adaptation, spreader and accessory cone selection, choice of sealer and spreader application. There is little clear evidence on how it is ‘best’ done (61, 83, 84).

Prerequisites

Canal preparation

Cold lateral condensation demands a canal which is continuously flared from apex to coronal opening (85). The superiority of apical stop or tapering control zone preparations for lateral condensation has not been investigated clinically.

Spreader selection

Condensing tools must be selected and tried into the canals before compaction begins. For optimal deformation of material through the length of the canal, a spreader must be pre-fitted which extends deeply into

Fig. 11. Accessory cones must occupy the space left by the spreader (A & B), otherwise an air or sealer-filled space will result (C).
Hand spreaders encourage higher compaction forces than finger spreaders (88), with the theoretical risk of root flexion or fracture (89). Nickel titanium spreaders may penetrate more deeply (90, 91), generate less internal stress (92) and distribute forces more evenly (93), especially in curved canals.

Lateral condensation works by vertical loading of the wedge-shaped spreader to move materials vertically and laterally. The greater the taper of the spreader, the greater the lateral component of force. Vertical loads in the range of 1–3 kg have been reported as typical (94), and adequate to deform gutta percha without undue risks to the tooth (88, 95). Forces associated with lateral condensation should not be a direct cause of vertical root fracture (88).

**Accessory cone selection**

In order to secure a dense filling, accessory cones must be able to fully occupy the space left by the compacting spreader (Fig. 11). They should therefore be the same size or slightly smaller than the selected spreader (84). Incompatibility will result in the accessory cone ‘hanging up’ before full insertion, resulting in a cement pool at best or a void at worst. *In vitro* evidence suggests that tapered gutta percha accessory cones may slide to length more predictably and be more forgiving in the hands of non-specialists than ISO accessory cones (84).

**Master cone selection**

There is no clear evidence whether ISO or unstandardized cones are preferred. Laboratory investigations (83, 87) suggest that ISO master cones allowed deeper spreader penetration and a larger number of accessory cones to be inserted, although this did not result in a superior seal against microbial leakage. Unstandardized cones may be trimmed to provide accurate apical sizing, and are usually tried in an irrigant-lubricated canal. Solvent dipping has been shown to improve apical adaptation and seal of master cones *in vitro* (96). This is typically achieved by immersing the apical 2–3 mm of the master cone in chloroform or halothane for 2 s before seating it to length in an irrigant-moistened canal (Fig. 12).

**Sealer selection**

It is not known which sealer works most effectively with cold lateral condensation, but clinical evidence suggests that sealer choice may not have a decisive impact on
outcome (61, 97). A slow setting sealer cement is generally preferred, which will allow adequate lubrication for accessory point insertion, and accommodate revision and consolidation of the fill if voids are detected on intermediate radiographs.

Leaving accessory cones with their tips immersed in sealer may soften them and compromise their ability to slide fully to length.

**Cold lateral condensation: the process (Fig. 13)**

Cold lateral condensation commences by liberally coating canal walls with sealer cement. In vitro evidence suggests that application with a spiral paste filler, fine injection needle, or an ultrasonically energized file ensures the most complete wall coverage (98–100), although application on the master cone, a paper point or a small file are popular alternatives. The master cone is slid to working length and the measured spreader applied under vertical loading for 10–60 s to deform material apically and laterally (101, 102). Optimal time of spreader insertion has not been scientifically validated in the clinical setting. Withdrawal is with watch-winding motion to ensure that the master cone is not pulled free, and the first accessory cone is slid promptly to length with a light coating of sealer. Compaction and accessory cone insertion continues, as the filling develops, each spreader insertion being slightly less deep than the previous one mirrored by shorter and shorter accessory cone insertion. Condensation usually continues until the spreader will reach no further than 2–3 mm into the canal (Fig. 13A). How closely general practitioners comply with such guidelines has not been scientifically evaluated.

Although the technique is described as cold lateral condensation, heat is always applied to sever the root filling at or below canal orifice level, and compact it apically with a cold plugger (Fig. 13B). This may soften and consolidate material several mm into the canal and improve seal (103).

**Variants on cold lateral condensation**

A number of measures have been reported to enhance gutta percha adaptation and density in lateral condensation. Examples include:

- Warming spreaders before each use in a hot bead sterilizer
- Softening gutta percha with heat before insertion of the cold spreader (104)
- Mechanical activation of finger spreaders in an endodontic reciprocating handpiece (105)
- Application of an ultrasonically energized spreader (106, 107), and
- Application of an engine-driven thermomechanical compactor which creates frictional heat and advances the material apically within the canal (108, 109).

Figure 14 shows a complex canal system filled by lateral condensation, supplemented with ultrasound.

**Appraisal**

Lateral condensation is regarded as safe, cost-effective and user-friendly, and case reports continue to be
published showing successful healing after its use in a variety of clinical scenarios (61, 110–114). A key limitation is when the root canal system has an abrupt change of diameter, as seen in internal resorption (Fig. 15). Such cases demand the application of heat to adapt gutta percha more thoroughly, or a reliance on large volumes of sealer in some areas of the canal. Adaptation may be equally limited in ribbon-shaped canals, where Kersten et al. (3) showed that clinical radiographs may not reveal poor filling density.

However, recent clinical reports have confirmed the ability of high-quality laterally condensed root canal fillings to exclude the oral flora after long-term exposure (115, 116) and it should also be noted that the majority of epidemiological studies on which we base our views on the predictability of root canal treatment have included canal filling by cold lateral condensation (117–123). Numerous other clinical trials from around the world involving cold (39, 124–133) and warm lateral condensation (134) have validated this approach in clinical practice. But how much of the observed success was directly attributable to the filling technique is not known.

A common criticism leveled at lateral condensation is that it is a time-consuming method, and this was borne out in a recent clinical study, where Thermafil obturation was found to be on average 20 min per tooth quicker (133).

**Warm vertical condensation**

Philosophical battles have long been waged between advocates of cold lateral and warm vertical condensation, presenting compelling cases on the benefits and shortcomings of each (135).

Warm vertical condensation was perfected and promoted by Herbert Schilder (136). His approach to filling was described as ‘3-dimensional,’ indicating an intention to fill all ramifications of the pulp space, rather than just the primary root canal, and the package of care to achieve this included clear guidelines on canal preparation, cone fit and condensation.

Contemporary advocates of this approach (137) list the criteria for satisfactory canal shaping as:
2. Original anatomy maintained.
3. Position of the apical foramen maintained.
4. Foramen diameter as small as practicable.

The tapered canal preparations thus created allow softened materials to enter anatomical complexities as heat and pressure are applied in a canal of rapidly diminishing diameter. Resistance to over-filling is achieved by the creation of an apical control zone as opposed to a traditional ISO ‘stop.’ Shaping is considered to be sufficient when a Fine-Medium or Medium cone (137) or other taper-matched cone (e.g., F2 for a ProTaper F2 prepared canal) can fit to length in the canal.

**Fig. 16. Scalpel-trimming an unstandardised gutta percha cone to conform to the ISO-gauged canal terminus diameter.**

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**Fig. 17. Markings on the master gutta percha cone produced by insertion of a file into an adjacent orifice indicates confluence.**

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Such preparations are now created rapidly and predictably with a range of hand and engine driven NiTi instrumentation techniques (138) and tapered, rather than ISO master cones are scalpel trimmed to fit snugly 1.0–0.5 mm short of an electronically confirmed canal terminus (Fig. 16), or constant drying point (139, 140). Snugness of fit is usually confirmed by slight resistance to withdrawal from the canal (short tug-back), indicating that the cone tip is binding at the preparation terminus (141). Resistance to withdrawal which continues beyond 1 mm may indicate that the cone is binding along a greater length of canal wall and not apically.

Canal confluence may be confirmed by the insertion of a cone to working length before inserting a file or spreader into the adjacent canal. Failure of the instrument to advance to length, or evidence of instrument markings on the side of the master cone indicates confluence (Fig. 17). The master cone for the second canal is trimmed to the point of confluence with a scalpel.

Sealer selection
Classic descriptions of warm vertical condensation have specifically advocated zinc oxide-eugenol sealers (Pulp Canal Sealer, Kerr, Romulus, MI, USA) which are believed to set rapidly in the event of extrusion and hopefully become inert in the periradicular tissues (16). There is, however, little clinical evidence that other classes of material, such as slow-setting epoxy resins may not perform equally well in warm vertical condensation.

Multiple wave warm vertical condensation
Plugger and heater-tip selection
In common with other filling techniques, condensing tools must be selected before treatment, and it is usual to select three or more pluggers which will extend progressively deeper into the canal, the narrowest extending within 4–5 mm of root-end (142). Nickel-titanium instruments such as the double-ended Buchanan or Dovgan pluggers may be better suited to curved

Fig. 18. Warm vertical condensation – multiple wave. Heating and compaction occurs in three or more stages (A–C), taking an increment of gutta percha from the canal each time and continuing until the apical 4–5 mm are ‘corked’ with gutta percha and sealer.
canals than stainless steel Machtou or Schilder pluggers.

Heat may be applied to the canal either with traditional 'heat carriers' which are warmed in a Bunsen burner flame, or more safely and neatly with an electronic touch-and-heat instrument. The instrument for delivering heat must have a narrow enough tip to reach within 5 mm of root-end.

Sealer application
Warm vertical condensation generates significant hydraulic forces and there is an increased risk that excess sealer may be extruded into the periradicular tissues (109). In contrast with cold lateral condensation, sealer application is therefore sparing, and often applied on the master cone, coating its length before insertion and seating to length initially before withdrawing to inspect that its entire surface (and therefore presumably the entire surface of the canal) has a light coating of sealer (16, 141).

The compaction process (Fig. 18)

Downpack
Compaction of the root canal filing occurs in multiple waves as the material is softened with heat and driven apically with cold pluggers. The first wave severs the gutta percha cone at canal orifice level, taking care not to withdraw the master cone from the canal. The largest cold plugger is then applied, gently condensing material around the walls of the canal entrance before positioning in the centre of the mass of gutta percha and compacting apically with firm finger pressure. Care should be taken to avoid contact of the plugger with canal walls, which is believed to carry an unacceptable risk of damaging force transmission to the root.

The second wave of heating follows, plunging the heat carrier or touch-and-heat tip 3–4 mm into the
mass of compacted gutta percha and removing an increment of material from the canal. Condensation proceeds in the same manner as previously, using the next plugger. Third and fourth waves of heating, material removal and compaction proceed in a similar manner until the apical 4–5 mm of the canal is ‘corked’ with thermally compacted gutta percha and sealer. Progressive heating and compaction is expected to drive gutta percha and sealer into all accessible canal ramifications during the downpack (143, 144).

**Backfill**
Empty canal space is most quickly and efficiently filled with injection-molded gutta percha, delivered from a gun in increments of 3–4 mm and compacted by hand to counteract cooling contraction. A variety of systems are available, including:

- Pre-heated carpule systems offering gutta percha in a range of viscosities (e.g., Ultrafil, Hygenic) (145) (Fig. 19). Such systems are relatively inexpensive, but offer limited working time before the carpule must be re-heated.
- Manual gun systems which work on the same principle as a glue gun, heating gutta percha pellets and maintaining heat to the point of expression from the gun (e.g., Obtura II), which offer the advantage of unlimited working time. Radiographically seamless union with the downpack is more likely to be achieved if the needle of the gun system touches the cut gutta percha surface in the canal and is held in place for 5–10 s before commencing backfill injection.

- New-generation engine-driven gun systems, in which temperature and flow rate can be regulated (Fig. 20).
- Systems incorporating downpacking and backfilling devices (Fig. 21).

Injectable gutta percha is commonly deposited in 3–5 mm increments, with further compaction, although one laboratory study supported the deposition of increments up to 10 mm (146).

Alternative backfill methods include the incremental addition of ‘backfill’ lengths of pre-trimmed gutta percha which are heated and compacted as in the downpack (147), and sealer-only backfills, which recent laboratory reports have suggested are superior to gutta percha compaction methods in terms of seal (74, 148).

**Single-wave vertical condensation (Fig. 22)**
System B was the first of a new generation of electronic heat carriers which allowed rapid heating and cooling of tips to facilitate their use as both heat carrier and plugger (Fig. 23).

**Tip selection**
System B is supplied with a variety of tips in 4%, 6%, 8%, 10%, and 12% taper, each marked at 5 mm intervals along their length (16) (Fig. 23).

A single tip is selected which will extend to within 4–5 mm of canal terminus before binding on canal walls. Following cone fit, sparing sealer application and cone insertion, the System B is set for maximal rate of heat increase and to a working temperature setting of 200°C. The cold tip is presented to canal entrance before activating the heater. Within 1 s, the tip has reached working temperature and is swept in one fluid movement over the course of 2–3 s until it sits 2 mm short of the binding point. At this point, the unit is deactivated, allowing the tip to cool rapidly, and pressure is maintained for 5–10 s on the cooling mass of gutta percha in order to counteract cooling contraction. The plugger now being locked into the canal by a solidifying...
mass of gutta percha, further heating is necessary to release the tip for withdrawal from the canal. The heater is therefore re-activated, classically by a 1 s ‘separation burst’ before smooth withdrawal. The apical gutta percha mass is then condensed further by hand before backfilling by any of the methods described previously (16).

**Evaluation of warm vertical condensation**

Compaction techniques of any sort require dentine removal to accommodate condensing instruments and the application of potentially damaging forces in non-physiological directions.

In warm vertical condensation, opponents have historically argued that the cost in terms of dentine...
removal to accommodate appropriate pluggers was excessive compared with that required for lateral condensation. This seems to be less of an issue in current practice with controlled canal flaring by contemporary instruments, and a welcome range of sufficiently narrow and efficient heat carriers, pluggers (including nickel titanium pluggers) and backfill needles.

Additional concerns have been raised with regard to thermal damage to the periodontal ligament during thermal compaction techniques, particularly if temperature guidelines are exceeded (149–152). Evidence on this appears to be equivocal (153, 154), with most of the modeling taking place in the laboratory setting where the heat-buffering effects of a richly perfused periodontium cannot properly be taken into account. There is little clinical evidence of adverse periodontal responses following thermoplastic obturation in clinical practice.

Perhaps as important are the questions of efficacy and control.

Many laboratory studies have addressed how well warm vertically compacted gutta percha adapts to canal walls and reduces sealer-pools following heating and compaction to different depths. The consensus of recent laboratory reports is that heating and compaction within the apical 2–3 mm of the canal is required for optimal gutta percha adaptation to the canal terminus (155–159), with significant (30%) differences in area of canal occupied by gutta percha following heat application to 2 or 4 mm from canal terminus (157). It is difficult to imagine that the majority of practitioners working in curved canals are able to consistently deliver heat and pressure to such depths, and in reality, many warm vertically compacted root canal fillings may comprise of a single, minimally distorted cone in the apical few millimeters.

Warm vertical condensation techniques are designed to drive materials into anatomical complexities (16), but a higher prevalence of sealer extrusion is recognized (109) with potential for further tissue injury and delayed healing. However, a recent clinical report (160) found no association between sealer extrusion and postoperative pain, whereas small extrusions of zinc oxide-eugenol sealers have been shown to resorb (161). A recent 20–27 year review on teeth with extruded of filling materials showed progressive periapical improvement with time (162).

Clinical studies (39, 109, 125, 132) and case reports (163, 164) have convincingly reinforced the view that warm vertical condensation techniques can enjoy comparable success to lateral condensation methods.

The impact on clinical outcome is central to our choice of techniques, and until recently, there has been little to separate established methods. However, data from a recent longitudinal study suggests that root canal treatments involving minimal apical enlargement and warm vertical condensation may be associated with higher successes than large apical preparations and cold condensation (165). Whether the filling technique or the overall approach to treatment was critical is hitherto unclear.

**Carrier systems**

Carrier systems represent another convenient means of delivering thermally softened gutta percha to canal...
systems with some degree of control. This approach is typified by Thermafil, which has developed from a method involving the coverage of a conventional file with regular gutta percha (166) to contemporary plastic carriers coated with flowable, reduced molecular weight gutta percha (167). Carrier methods and may be considered low temperature techniques with little risk of overheating tissues (168).

Clinical application (Fig. 24)

Verifying the preparation
In common with other techniques, the compacting tool (in this case, a plastic blank, which in the filling devices is covered with gutta percha) must first be tried in the canal to ensure that it will be able to carry and compact material to full length. This takes special importance in the case of carrier systems, where insertion occurs in one action, with little opportunity to revise the result if the carrier does not go to length first time.

Products from different manufacturers have differing degrees of taper, which may make some systems more suitable with certain canal shapes than others.

Whole systems are available with matched shaping instruments, absorbent points, and carrier devices (40, 169).

Such systems introduce an element of ergonomics to root canal treatment and may be welcomed by many. The relative success of such systems in different configurations is largely unknown.

Preparing the device
The majority of practitioners probably use Thermafil and other devices as supplied.

As there is usually an excess of gutta percha on the carrier, and as the excess apical to the tip of the plastic carrier is not accurately known, some choose to:
- trim back the apical extent of gutta percha until 1.5 mm of the tip of the carrier is visible, with the reported intention of allowing more accurate carrier control during insertion and limiting excess gutta percha extrusion beyond the root apex (16) (Fig. 25)
- Remove the most coronal 2–3 mm of gutta percha from the carrier, with the intention of limiting

![Fig. 25. A Thermafil device prepared for use. Upper device unaltered; lower device trimmed to remove excess gutta percha apically and coronally.](image)

![Fig. 26. (A) Resilon, a biodegradable polycaprolactone with (B) matching sealer.](image)
excessive gutta percha in the pulp chamber (16) (Fig. 25).

It is critical for the development of adequate flow and to facilitate insertion that the device is heated to the correct temperature, and for the required time in the manufacturer’s recommended oven.

**Sealer application**

The insertion of a well-fitting Thermafil device is akin to inserting the plunger of a syringe to the root canal. As a consequence, and in contrast to cold lateral condensation, where excess sealer will slowly migrate coronally, excessive sealer application should be avoided to reduce the risk of large-scale apical extrusion.

Sealer is generally applied sparingly on a paper point, with the subsequent insertion of further dry paper points to ensure that excess has been removed and that there is even, light wall contact (16).

**Carrier insertion**

When the carrier is adequately heated, it is removed from the heater without delay or distraction and smoothly seated to full working length in one smooth, fluid movement.

In the hands of skilled and experienced operators, the extent of gutta percha and sealer movement can be controlled by the rate of carrier insertion (G. Cantatore, personal communication, 2005), and laboratory evidence (170) has suggested that more rapid insertion captures apical detail better than slow insertion.

Condensation pressure may be applied with a small plugger to compensate for some of the shrinkage which inevitably accompanies cooling. The shank may then be severed with a bur or heated instrument.

**Evaluation**

Laboratory evidence suggests that Thermafil obturation is a low-pressure technique (171, 172), capable of rapid, and dense filling of root canal systems and their ramifications (11, 173–175).

Periapical extrusion has again been identified as a potential drawback of Thermafil (175) and Da Silva et al. (176) have therefore described a modified carrier obturation technique in which a sealer-coated master gutta percha cone is first inserted to length before the heat-softened carrier. This method has been shown in vitro to create dense root canal fillings while controlling apical extrusion of materials, and presumably, after pain.

Two clinical trials have been reported recently. Gagliani et al. (177) have shown 94.9% periapical health in teeth with apical periodontitis, and 48.2% healing in teeth without apical periodontitis, 24 months after treatment with Profile and Thermafil, whereas Chu et al. (133) showed comparable, 80% success at 3 yr review in teeth filled with Thermafil or lateral condensation. Lateral condensation was, however, found to take 20 min longer on average per tooth than Thermafil.

Carrier devices are firmly established in clinical practice, and are reported to be especially effective in long, curved canals, where the insertion of conventional spreaders and pluggers may be compromised (167).

**Resilon (Fig. 26)**

Despite apparently satisfactory performance over many decades, and in a variety of guises, gutta percha and sealer filling techniques do not represent the universal ideal. Although few materials, with the exception of MTA, have seriously challenged gutta percha and sealer in the majority of filling situations, research continues to find alternatives which may seal better, mechanically reinforce compromised roots, and avoid any potential for adverse responses in latex-allergic patients.

Resilon, a polycaprolactone core and sealer filling system has recently entered the market as Real Seal (Dentsply, Tulsa, OH, USA), Epiphany (Pentron, Wallingfort, CT, USA) and Resilon Simplifill (Light-speed Technologies). Cones of ISO and increased taper, and pellets for injection-molding are available, with the recommendation that the material can be used in any conventional technique. Melting temperatures are, however, reduced to 150°C for System B, and to 140°C for Obtura (178). Anecdotal reports suggest that the material is user-friendly but does not retain its softness after heating as well as gutta percha. Components were developed to bond with each other and with canal walls to produce an hermetically sealing (19) and root-reinforcing (18) monobloc of material. Claims on the in vitro sealability of Resilon were recently challenged by independent researchers (178), but recent clinical research in dogs has confirmed that Resilon provides a better coronal seal against microbial ingress than laterally or vertically compacted gutta percha with AH26 (179). Clinical studies in humans are awaited.
Conclusions

Although the importance of root canal filling should not be diminished within a package of infection-controlling care, clinical trials have failed to identify filling methods as significant in endodontic outcome (39, 109, 129, 132, 133). Meta analysis has also provided little evidence that endodontic outcomes have improved with time (180), indicating that the explosion of technology in endodontics may have met needs other than those of simply healing more disease. Recent case reports demonstrate the extraordinary skills of contemporary endodontists, but the message of the case reports demonstrate the extraordinary skills of other than those of simply healing more disease. Recent case reports demonstrate the extraordinary skills of contemporary endodontists, but the message of the case reports demonstrate the extraordinary skills of other than those of simply healing more disease. 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