

Anatomy of an overfill: a reflection on the process

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The design and implementation of shaping, cleaning and sealing objectives in root canal therapy are fraught with real and potential pitfalls when the anatomic complexity of the space and technical considerations for its instrumentation, disinfection and obturation are contemplated. This review will focus on the genesis of results that lead to endodontic overfills. We will look at how the literature defines overfill and overextension; attempt to address the consensus opinion on the definition of working length; and determine the effects of shaping geometry on overfill as well as the biological impact of obturation materials that go beyond the root canal space. In addition, this manuscript will highlight evidence for the prevention of overfills as well as focus on the local factors that affect repair and healing.

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*It is possible to fail in many ways . . .
while to succeed is possible only in one way.*

Aristotle

Introduction

Root canal anatomy and the confounding nature of human pulpal systems provide the majority of significant challenges in rendering endodontic therapy. The first priority of effective therapy is to enter, shape and clean the system in a manner that will allow efficient and total filling of the root canal space. In the past two decades, we have witnessed increasing innovation in the science and technology of endodontic therapy. These advances are helping to address the complex nature of the pulpal space by safer and enhanced methods. Thus, these improvements have lessened the chances for iatrogenic problems but have not eliminated them.

In a decade-old consensus report of the European Society of Endodontology regarding quality guidelines for endodontic therapy, it is clearly recommended that 'the objective of any (endodontic) technique used should be to apply a *biocompatible* hermetically sealing canal filling that obturates the prepared canal space from pulp chamber *just to its apical termination*' (1). If the final objective of root canal therapy is to render the root canal space impervious to leakage and microbial recontamination, then the sealing of the space becomes

an important consideration in the long-term healing outcomes and the health and safety of the patient.

The design and implementation of shaping, cleaning and sealing objectives are fraught with real and potential pitfalls when the anatomic complexities of the space and technical considerations for its instrumentation, disinfection and obturation are contemplated. How do we create the shapes we want in a safe and biological manner and then how do we insure that those shapes will be completely and reliably filled with consistent long-term healing outcomes?

This review will focus on the genesis of results that lead to endodontic overfills. We will look at how the literature defines overfill and overextension; attempt to address the consensus opinion on the definition of working length; and determine the effects of shaping geometry on overfill as well as the biological impact of obturation materials that go beyond the root canal space.

Apical termination of obturation

The determination of the apical limit of obturation is not universally agreed upon in conventional endodontic circles. The most forthright thing you can say about the exact point at which to finish root canal shaping . . . *is that the anatomy is unpredictable . . . and the positions we choose to fill our root canals are inconsistent.*

Many authors would like to set the limits of working length at the cemento-dentinal junction (CDJ), where

anatomists demarcate the periodontal tissues becoming pulpal tissues as they course up through the pulp space proper. This position is described in histological sections that are sliced parallel to the pulpal axis through the apical foramen. The CDJ is usually constricted in anatomical sections and is regularly named for its functionality as the apical constriction or the narrowest diameter at the apical end of the pulp space. Often, the exact apical constriction or the narrowest diameter, if one exists, does not coincide with the exact anatomical position of the CDJ. Kuttler (2), in his classic 1955 anatomical study of 402 healthy root apices, described the union points of the cementum, dentin and canal as the CDC or the 'cemento-dentino-canal.' He commented in his manuscript that this anatomy, which culminates in a cemental funnel beyond the minor diameter, would present difficulties when attempting to create a hermetic filling of the root canal (2).

However, the CDJ is considered by many to be the contemporary nomenclature for this apical position and the location most ideally suited to finish the shaping and cleaning procedures of the canal as well as the termination point for obturation. This focal point for all endodontic treatment has been understood to vary from 0 to 3 mm from the radiographic apex of the root and presents a formidable challenge when clinicians attempt to use imaging and electronic location technologies to determine this histologic position within the root canal (3, 4).

Because this area represents the point where all condensation forces are directed in an effort to three-dimensionally seal a root canal space, the unique characteristics of this region require specialized understanding. It is additionally important to understand the arguments that are made by endodontists to instrument beyond this constriction to the radiographic apex or short of this position to create an apical stop or a zone of containment within the canal.

The microanatomies of the root apices of central incisors were examined and measured to determine the amount of skewing or distortion that occurs in the longitudinal position of the apical constriction around the circumference of the canal. Olson et al. (5) found a significant skew of $> 100 \mu\text{m}$ in the incisio-apical extent of the constriction. Others have found irregularities in the shape of the CDJ, describing variations of oval, round and ribbon shapes (6) (Fig. 1). Knowing that the apical constriction is not of uniform depth at all points

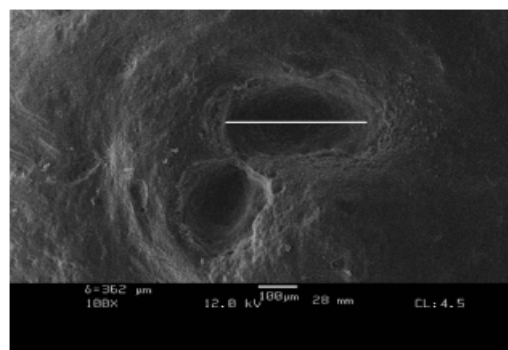


Fig. 1. Scanning electron photomicrograph of the apical foramina on the mesial root of an upper molar. Elliptical and oval anatomies are seen in this sample. Courtesy of μCT ApexViewer, University of Zurich, Peters OA, Radzik EF, eds., 2008.

around the canal but in fact uneven in the longitudinal direction as well certainly has an implication on the accurate determination of the pre-eminent position to end working length within the canal by any method (4, 7, 8). Considerable variability has been observed in the diameters measured at the apical foramen, the apical constriction and the CDJ. In addition, the amounts of cementum extending into the root canals varied considerably in research assessing maxillary teeth (9).

It is meaningful to understand that there are dynamic variables in anatomical measurement studies of teeth that impact the shapes and contours of the foramen such as age, occlusal influences, inflammatory influences and the very experimental methodologies used to elucidate the anatomy. All of these variables will have an effect on the findings (2, 10–12) (Figs. 2a and b).

The importance of the variation in the position of these three locations (foramen/CDJ/constriction) has created the ongoing controversy in endodontics concerning where to finish the preparation (Fig. 3). Ardent supporters of shaping and filling to the radiographic apex are at odds with an equally determined faction that supports shaping and filling to a determined level within the canal space short of the radiographic apex (3, 8) (Figs. 4a and b). Those who shape to the radiographic apex argue that working short of the full radiographic length may lead to incomplete elimination of pulpal remnants and infectious bioburden. Those who argue for shapes that should be contained within the root structure point to healing outcomes and studies that support working within the terminal 2 mm of the canal space rather than

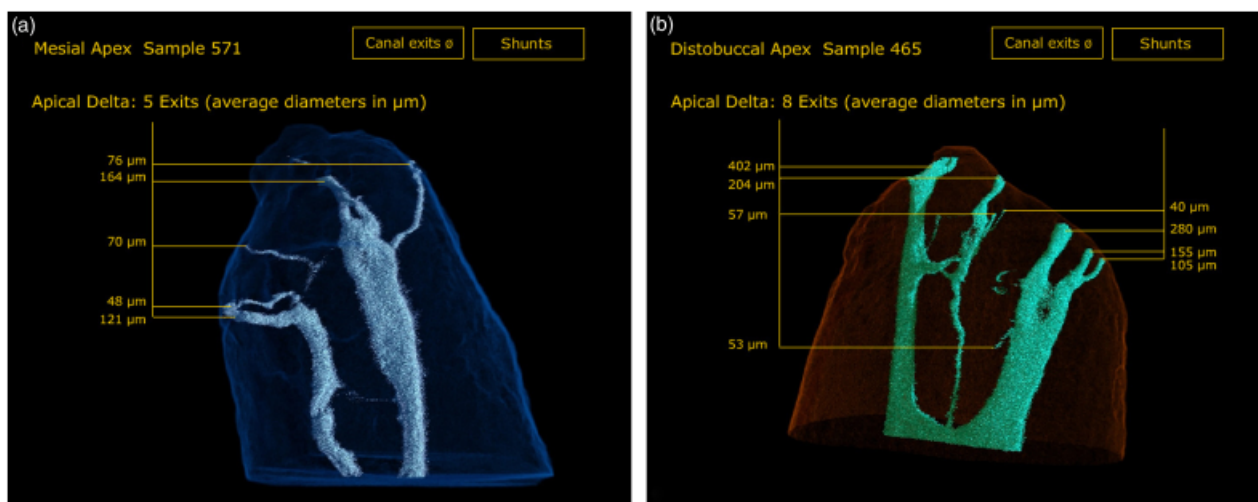


Fig. 2. (a) μ CT scan of the mesial root of an upper molar denoting the dimensions of the canal exits. (b) μ CT scan of the distal root of an upper molar denoting the dimensions of the canal exits. Images courtesy of μ CT ApexViewer, University of Zurich, Peters OA, Radzik EF, eds., 2008.



Fig. 3. A well-shaped and obturated maxillary molar that reproduces the apical anatomy responsible for the existing pathosis and is a remarkable example of the ‘Art of Endodontics.’ Courtesy of Dr. Sherry Bloomfield.

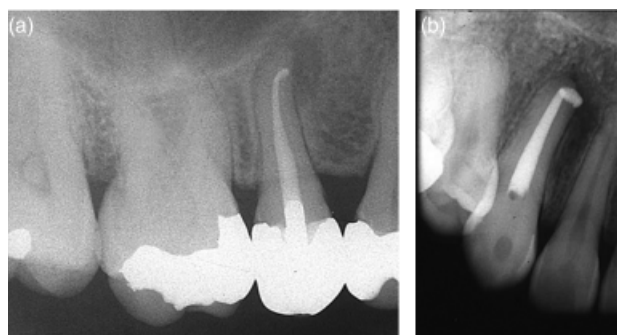


Fig. 4. (a, b) Examples of canal termini that do not end at the radiographic apices of the teeth.

creating a potential impingement outside this zone, which may delay wound healing (7, 8).

The advent and evolution of electronic technology has made the exact location of these contested positions far more scientific and undeniably less empiric when used clinically. With modern apex locators, practitioners can reliably determine an electronic measurement that conforms to their thinking about the required position of their working length in relation to the apical foramen, and then, during shaping, purposefully establish the apical limit of their preparation and obturation (13–16).

Defining overfilling and overextension

In his classic contribution to the 1967 edition of *Dental Clinics of North America* on ‘Filling Root Canals in Three Dimensions,’ Professor Herbert Schilder defined the distinction between overfilling and underfilling, and overextension and underextension (17). These definitions have remained unchanged over the past 40 years. Dr. Schilder described the *overextension* or the *underextension* of a root canal filling as being solely a matter of its vertical dimension: beyond or short of the root apex.

The *overfilled* canal was one that was well filled in three dimensions but exhibited surplus filling material



Fig. 5. (a) Apical pathosis associated with an upper lateral incisor requiring endodontics. The etiology was due to a 'dens in dente'. The lesion was expansive and encompassed several teeth. (b) The root canal was obturated with an extensive amount of ZnOE sealer extruded. (c) Ninety days post-operatively, the sealer is disassociated from the apex and being absorbed. (d) Six months post-operatively, the sealer is almost completely absorbed and bone fill is evident. (e) One year after obturation, bony architecture is almost completely restored.

past the apex. The *underfilled* root canal fails to seal the circumference of the apical foramen in one or more dimensions, leaving reservoirs for stagnation of fluids, recontamination and persistence of infection. Dr. Schilder argued that the final test of a root canal filling was its capacity to seal off the root canal system from the periradicular tissues and that the ultimate compatibility of our materials would not affect the healing process in the event of an overfill (17) (Figs. 5a-e).

Apical size and the geometry of shape

Complex root canal anatomy should be considered one of the most significant challenges in creating root canal shapes that will support good obturation outcomes. After biomechanical instrumentation, the completed

root canal shape needs to withstand the internal compressive forces of obturation and provide a sufficient resistance form to contain softened and compressible filling material. In a series of morphometric measurements on anterior and posterior teeth, Kerekes & Tronstad (18-20) found a wide range of measurements at the apical constriction of all teeth.

In a study that questioned our understanding of the true horizontal diameters necessary to clean the terminus, Jou et al. (21) coined the term '*working width*' to alert clinicians to the critical need to understand the horizontal dimension of the apical size and its clinical implication in cleaning the apical terminus.

Current shaping strategies used by clinicians align with two general trends in contemporary endodontic

practice. A significant number of practitioners believe that enhanced apical instrumentation and larger apical diameters with minimal taper in the canal shape lead to extrusion of materials and a loss of control over the obturation component of the treatment. They advocate smaller apical preparations, continuous taper and a preparation that promotes a resistance form and a tight apical seal. The arguments are strategic and technique driven, often supported only by clinical outcomes, and their impetus has been directed at the obturation phase of endodontic therapy (13–16).

However, there is a significant body of literature which presents evidence that larger apical canal diameters are important to shape the apical canal wall, flush debris, allow deeper irrigation to the terminus and decrease the remaining bacterial contamination in the system (22–28). Studies vary on which size diameter will accomplish maximum cleaning. Some researchers have shown that file diameters must range from #35 to #45 to accomplish significant bacterial reduction. Others have shown that minimal sizes can accomplish this task as adequately as larger diameters (29, 30).

What is remarkably clear from the evidence is that, no matter which school of thought one ascribes to, it is not possible that any apical preparation technique will render the terminus entirely free of bacterial contamination in an infected canal (31–32).

Weine et al. (33) and others (34, 35) have described and elucidated the clinical damage and preparation errors that can occur while shaping root canals to large sizes with stainless-steel instruments. Transportation, ledging, apical perforation and loss of the original canal position are all well-recognized shaping errors that often lead to loss of working length and damage to the apical terminus. Most of these lapses increase the likelihood of the extrusion of filling materials at the time of obturation (Fig. 6).

There is now a large body of innovative research quantifying the use of rotary and hand nickel–titanium instruments first described by Walia et al. (36) which report that the use of this super-elastic metal alloy offers less straightening and better centered preparations compared with traditional stainless-steel instruments in preparing the wide range of anatomical variability seen in teeth (37–42).

These studies have focused on the geometry of shape produced by these instruments alone or in combination with stainless-steel, including conicity, taper, flow and maintenance of the original canal position. Most of

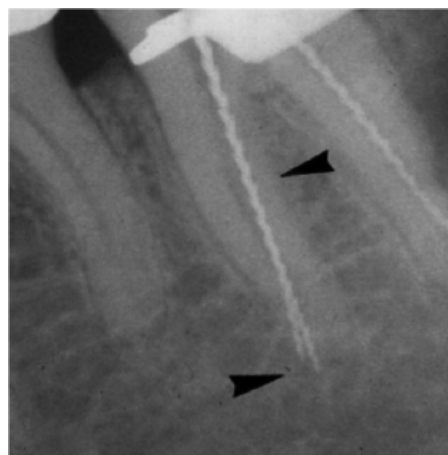


Fig. 6. Typical transportation of the mesial roots of a lower molar after improper shaping. Instrumentation has moved the canal space off the center axis, resulting in a zipped and perforated root terminus and a weakened radicular structure.

these studies have recorded the degree of change from the original position and have noted loss of original canal positions as ledges, zips and apical elbows based on the original definitions by Weine et al. (33). In comparing stainless-steel vs. nickel–titanium, researchers have focused on both the metallurgy of the systems and the systems themselves (42, 43).

Considerations to manage working length

If a creditable controversy in root canal treatment is the apical end point of the working length, there is no disagreement in contemporary endodontics that obturation beyond the apical foramen should be avoided because it is so often associated with a reduced success rate or delayed healing (8, 44–48) and exposes the patient to the potential for injury (49).

Apical patency

As described earlier, most clinicians prefer to end the biomechanical instrumentation at the apical constriction (narrowest point in the canal at approximately the CDJ) (50), where the contact between root canal filling material and the apical tissues is minimal. In addition, many dentists practice apical patency with small passive files (13) in order to maintain communication with the apical tissues and prevent canal blockage and ledging

coronal to the determined end point. Goldberg & Massone (51) have shown that a patency file should be as small as possible to avoid transporting the foramen in teeth where it emerges laterally from the apex.

Even though there is no scientific evidence that using a patency file improves the success rate of root canal treatments, many clinicians use small patency files to enhance treatment of the canal terminus without transportation or enlargement (52). While most clinicians think of apical blockage as blockage by dentinal debris, it is more often caused by the collagen remnant at the apical end of an extirpated pulp. This collagen stump is compacted by files into the constriction (13). This can be a vexing clinical problem as often this apical pulp stump will be contaminated by organisms. Without removal, it will continue to contribute to symptomatic inflammation post-operatively, even when the completed root canal appears to be of good quality radiographically (13).

The concept of apical patency and the resulting passage of patency instruments through the apical foramina of root canals are still controversial issues for a small minority of endodontic practitioners. They cite concerns about the extrusion of apical debris, inflammation and post-operative pain. Yet, good research over the years has shown that all instrumentation strategies cause the extrusion of apical debris even when filing is kept short of the apical foramen by at least 1 mm. To date, there is no evidence that the practice of apical patency has a direct association with increased exacerbations or inter-appointment flare-ups associated with this debris extrusion.

Apical patency has been studied for its effect on extrusion of debris and canal transportation (51, 53, 54). There is a trend that as the apical diameter is increased by larger patency files, debris extrusion also increases. Because the vast majority of clinicians do not use a patency file to enlarge the constriction, patency itself, especially with small files, appears to have no enhanced impact on debris extrusion (51). Similarly, studies that looked at apical patency and the ability to limit canal transportation showed that it had a minimal effect on the prevention of canal transportation (55).

Imaging

Despite the limited three-dimensional information provided by a conventional radiograph, radiography remains the commonly used standard for working

length determination (56, 57). It is well reported that the radiographic image depends on the quality of the beam, the type of film, the angulation of exposure and the method of development if using a traditional film.

While concerns still linger regarding the image quality of digital radiographs compared with a traditional film, these concerns are diminishing with the improving technology, magnification possibilities (58, 59), digital subtraction (60), reduced radiation exposure, real-time images and archival benefits (61). The ability to manipulate the image that is on the computer screen is what allows digital imaging its genuine power to aid in identification of treatment outcomes.

Electronic apex location

The universal acceptance of electronic apex locators is a clinical reality with the current incorporation of devices well into their fourth generation. These modern devices have helped make the non-radiographic measurement of root canal length more accurate under a host of varying clinical circumstances. Generally, a distance of 0–2 mm between the radiographic apex and the obturation material marking the end point of root canal instrumentation has been designated as acceptable when evaluating post-operative radiographs. Accordingly, in a retrospective study that investigated the influence of the level of apical obturation on the treatment outcome (46), a root canal filling was considered satisfactory if, among other factors, its apical level was 0–2 mm short of the radiographic apex; this apical level contributed to the highest success rates.

Stein & Corcoran (62) discussed the possibility of unintentional overinstrumentation when radiographs alone were used for working length determination. They reported that the position of a file placed for working length determination appeared radiographically 0.7 mm shorter than its actual position. The results of another investigation suggest that a working length that ends radiographically 0–2 mm short of the radiographic apex does not guarantee that instrumentation beyond the apical foramen will be avoided in premolars and molars. The authors conclude that radiographic measurements should be combined with electronic working length determination using modern apex locators to better help identify the apical end point of root canal preparation and avoid overinstrumentation (63).

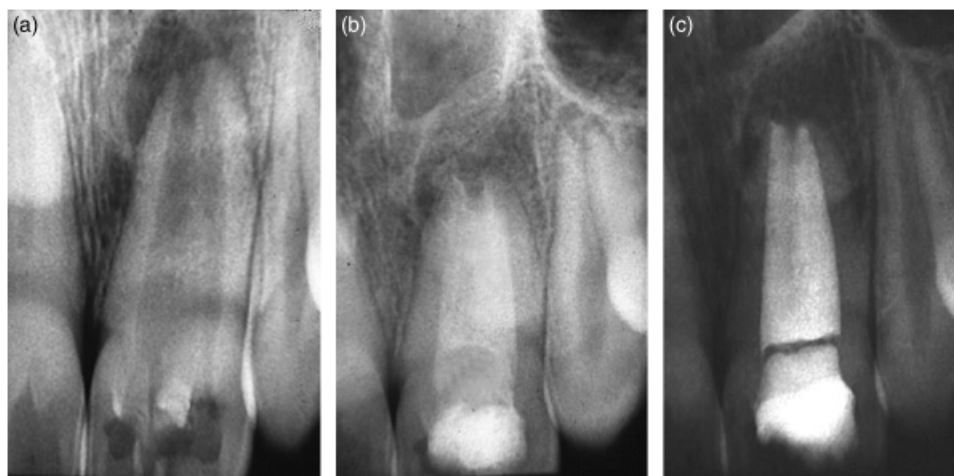


Fig. 7. (a) Geminated central incisor with a large periradicular infection. (b) Calcium hydroxide was used in conjunction with irrigation as an inter-appointment medicament to reduce the intraradicular bioburden in such a large pulpal space. (c) Three-dimensional obturation.

Wrbas et al. (64), in an *in vivo* study using two different electronic apex locators, were able to determine the minor diameter of teeth before extraction in 75% and 80% of the same samples, respectively. Shabahang et al. (65), in a study with a similar experimental design using a single apex locator, found a high degree of accuracy in determining the minor diameter.

In a recent review of the literature on the role of apical instrumentation in root canal treatment, Baugh & Wallace (50) concluded that, because the apical dimensions of root canals range from very large to very small, the clinician should seek instruments and techniques that can help determine when instrumentation to the correct apical size has been achieved and that additional research was necessary, given the controversy which still remains regarding the final apical size. Other researchers have shown the importance of combining therapies such as rotary instrumentation using larger apical sizes with the use of calcium hydroxide to reduce the amount of bacteria in root canals and increase long-term success (66) (Figs. 7a–c). In a recent meta-analysis of studies performed over the last three decades on optimal obturation length, the results demonstrated that obturating materials extruding beyond the radiographic apex correlated with a decreased prognosis for repair (67).

Inflammatory and toxic effects of root canal materials

Currently, there is an important body of convincing biological literature that lends confidence to the

science describing host tissue reaction to many endodontic obturation materials. The following conclusions regarding endodontic sealers have stood the test of time in the last half century (68).

1. All obturation sealers are irritants in their freshly mixed states.
2. After setting or curing, some sealers lose their irritant components and become relatively inert.
3. All sealers are absorbable.
4. Components of sealers will be managed by the immune system in the process of absorption (68, 69).
5. Pastes intended to fill the entire root canal system will be absorbed more rapidly than solid core obturations with sealers (70).
6. A minimum amount of sealer should be exposed to periapical tissue.

In endodontic therapy, sealers and cements are primarily used to fill any irregularities at the interface between the solid core root canal filling material and the walls of the canal system, ideally rendering the system impervious to bacteria. Endodontic failures caused by a continued re-growth and proliferation of microorganisms due to apical percolation of blood-borne proteins can still occur even in properly cleaned and shaped teeth if the apical foramen is poorly sealed. It has been reported that even in the absence of microbial factors, root-filling substances can induce a foreign body reaction, leading to the development of periapical lesions that may be refractory to endodontic therapy (71).

Many sealers, when used properly, are recognized to have antimicrobial activity as well as the potential to

stimulate fibroblastic, osteoblastic or cementoblastic activity. Sealers can be grouped based on their primary constituents, such as zinc oxide–eugenol (ZOE), calcium hydroxide, resins, glass ionomers or resin/composite-based sealers.

The biological and irritational properties of root canal sealing materials can be evaluated in a number of ways. These have included tissue and cell culture studies (72–74), bone and soft tissue reactions to set and unset implanted materials in experimental animals (75–77), experimental and clinical studies on animals and humans (78–80) and new assessments involving histochemical analysis and X-ray microanalysis (81–83).

Early investigations into the absorbability of root canal sealers in animal models showed that very hard and compact sealers with low solubility became encapsulated by fibrous connective tissue (70). Less dense and more soluble sealers were dispersed and absorbed more rapidly. Large quantities of excess filling materials in the periapical tissues caused necrosis of bone, followed by bone resorption and then absorption of the filling materials. Most root canal sealers produce an initial acute inflammatory reaction in the connective tissues (68). This is followed by the production of a chronic foreign body reaction in which phagocytosis is a recognized feature. As the material disintegrates in tissue fluids, macrophages are a predominant element in the removal of the foreign body. Such evidence suggests that the presence of foreign material in large quantities in the periapical tissues causes persistence of breakdown and this persistence is fueled by the toxicity of the engulfed material. In particular, the breakdown products may have an adverse effect on the proliferation and viability of periradicular cell populations that are necessary for repair (83).

It is the sealers and components of sealers which are recognized by the scientific literature as neurotoxic or highly irritating that warrant more scrupulous attention and an equally careful recognition of their potential for serious injury.

Gutta-percha

The most common core material worldwide is gutta-percha. It has a history of usage in dentistry of well over a century and is chemically considered a polyisoprene (a crystalline polymer). In its clinical formulations, it comprises approximately 20% of the total volume, with

the remainder mostly zinc oxide and proprietary additives. Gutta-percha has a low degree of toxicity when compared with other components used in endodontic obturation and has successfully persisted in clinical usage (84). Because of the tissue tolerance of gutta-percha, extrusion of the material in and of itself should not impair tissue healing (46).

Resilon

A new root-filling material, Resilon (Resilon Research LLC, Madison, CT, USA), has been introduced into the marketplace in recent years. Derived from polymers of polyester, it contains bioactive glass and radiopaque fillers. Resilon is recommended for use in combination with a new dual-curable dental resin composite sealer Epiphany Root Canal Sealant (Pentron Clinical Technologies LLC, Wallingford, CT). Resilon has the same handling properties as gutta-percha. The Resilon core materials are similar to gutta-percha cones. The cytotoxicity of Resilon and Epiphany was evaluated in tissue culture (85). Inflammation was most severe in the first 48 h due mainly to Epiphany. Inflammatory reactions decreased after 2 days to reach a level comparable with commonly used root canal sealers (85). In another study using human gingival fibroblasts, Resilon alone was no more cytotoxic than gutta-percha (86).

Eugenol

Eugenol is a phenol derivative and a major component of the numerous formulations of sealers that incorporate this liquid into a zinc oxide powder for placement with a solid core obturation. Most ZOE sealer cements are cytotoxic and induce an inflammatory response in connective tissues. As a component, the liquid exhibits an inhibition of sensory nerve activity. Because of its long-time use as a sedative or anodyne in dentistry, eugenol has been an integral component in modern dental therapeutics. It is also currently recognized that, if misused, eugenol can be highly inflammatory and destructive.

In a study to determine the effects of eugenol on induced nerve impulse transmission, concentrations of eugenol as low as 0.05% were applied to frog sciatic nerve using a standard experimental model. All concentrations were found to reduce and finally eliminate the amplitude of the nerve's induced compound action potential. The author concluded

unequivocally that eugenol is toxic to nerves (87). Other researchers have shown similar neurotoxic effects of eugenol in sealers using other experimental animal models (88).

Calcium hydroxide

Calcium hydroxide sealers have been promoted for their ability to stimulate repair. These claims have yet to be proven. Rather, the inclusion of calcium hydroxide should be assessed for its efficacy in creating a long-term seal of the root canal space and its inflammatory effects on periapical tissues and neurologic structures. In one study, calcium hydroxide root canal sealers produced an irreversible blockade of rat phrenic nerve conduction upon a 30-min application (89). In another, the investigators found complete inhibition of rat sciatic nerve after 50 min of exposure to a calcium hydroxide sealer. They observed partial recovery after perfusion with a saline solution (90).

Paraformaldehyde

The use of paraformaldehyde pastes depends on the acceptance of concepts and therapies related to the principles of mummification and fixation of pulp tissue (91). In 1959, Sargenti & Richter introduced a method for endodontic therapy that included filling the root canal system with a paraformaldehyde paste (N2). Sargenti and other proponents of paraformaldehyde paste formulations have touted the consistent antimicrobial activity of the paste when used in endodontic therapy (92). While traditional ZOE sealers are used in conjunction with solid core material such as gutta-percha, N2, RC2B and Endomethosone, Spad and other paraformaldehyde paste formulations have been traditionally recommended as the sole filling material, greatly increasing the volume of material used in the canal system. Thus, absorbability and toxicity are serious considerations with paraformaldehyde pastes. In a large number of reports published regarding paresthesia and other complications of the inferior alveolar nerve following penetration of root canal filling material into the mandibular canal, in most cases, damage to the nerve was specifically attributed to the highly irritating components of various paraformaldehyde pastes (93–99). Brodin (100) and other investigators (80, 101–105) have experimentally and convincingly demonstrated the neurotoxicity of these paraformaldehyde compounds. Furthermore, Brodin

et al. (106) have shown that N2, among other root-filling materials with paraformaldehyde as a component, produced permanent disruption of nerve conduction *in vitro*. It had been recognized early on by researchers that every effort should be made to confine these materials to the canal (95, 101–103) as more and more clinical reports of extreme complications were published (80, 96, 99, 107).

Because of the higher risks associated with paraformaldehyde-containing endodontic materials, the use of N2 or a similar type of pastes are contraindicated because the risk of permanent injury is substantially less with traditional filling materials. When a safer, less hazardous alternative therapy exists, it is unreasonable to elect to use an unsafe methodology.

Even the most acceptable materials can cause serious injury if extruded in large volumes into sensitive structures. Pastes and sealers that contain paraformaldehyde or known safer materials are difficult to control and may additionally create injuries in the maxillary division of the trigeminal nerve when extruded through maxillary teeth or into the sinus membranes (108–110) (Figs. 8a–c).

Polymers, resins and other sealer options

A number of currently available sealers are variations on a resin/polymer formulation. This makes them options in their own right, or they are a choice when resin bonding within the canal is proposed, and the effects of eugenol on dentin are not desired as a contaminant in the bonding process.

AH26, AH26 Plus (Caulk/Dentsply, Milford, DE, USA) is the most commonly known sealer in this category. The sealer is reported to have good handling characteristics, seals well to dentin and can be used effectively with heat during obturation. The sealer has been reported to be very toxic upon initial mixing (73, 111). This toxicity resolves rapidly during the setting process, and after 24 h the sealer is reported to have a relatively low toxicity. Spangberg et al. (111) have reported that this initial toxicity was due to the formation of a very small amount of formaldehyde as a result of the chemical setting process. They described the release of formaldehyde as thousands of times lower than conventional formaldehyde-containing sealers such as N2, and stated that after setting there was little toxic effect.

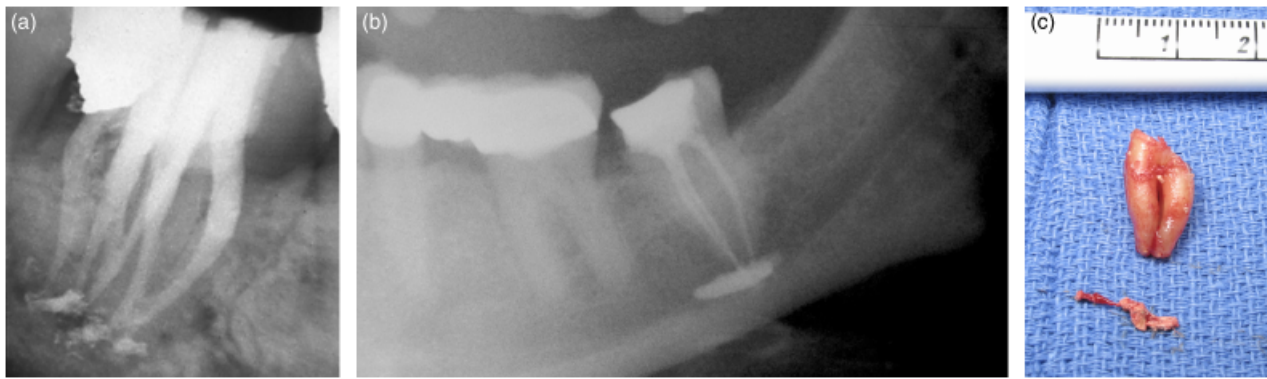


Fig. 8. (a) An 'acceptable' overfill of a lower molar with a ZOE sealer, demonstrating a three-dimensional seal and obturation to the root termini that is unlikely to prejudice the healing process. Courtesy of Dr. John Munce. (b) An 'unacceptable' overfill demonstrating a paraformaldehyde paste into the inferior alveolar nerve canal (2006). The patient experienced symptoms of burning pain and anesthesia that prompted surgical intervention weeks later. (c) After extraction of the tooth and removal of the overfill, the patient still experiences burning pain and continuing anesthesia.

Diaket (ESPE, Seefeld, Germany) is a polyketone compound containing vinyl polymers that, when mixed with zinc oxide and bismuth phosphate, forms an adhesive sealer. It has been demonstrated that it is relatively toxic during setting and these effects are persistent (73, 83).

Epiphany (Pentron Clinical Technologies LLC) is a new dual-curable resin composite sealer (multi-methacrylate). It is recommended for use in combination with Resilon. The sealer was initially found to be very toxic in cell culture (112). When compared with AH Plus, initial toxicities were similar and severe; however, Epiphany, when set, remained moderately toxic while AH Plus was non-toxic (112). Another study found only minor inflammatory reactions to Epiphany in an animal model (113).

Resorcinol-formalin resin is a paste filling material that is commonly used in Russia, China and India for the treatment of pulpitis. Although there are many variations of the resin pastes that are used, the main ingredients are resorcinol and formaldehyde. The principle behind 'resinifying therapy' is that of a liquid phenolic resin being used which will solidify by polymerization after being placed into the root canal. The residual pulpal remnants are claimed to be 'resinified' and to be 'rendered harmless' (114). However, when set, this material creates an almost impenetrable barrier and renders the tooth structure a deep brownish to red color. Because of remaining pulp tissue in the apical part of the canal, complete absence of cleaning and shaping procedures and/or failure of the resinifying agent to reach the apical portions of the

canal, this treatment may eventually fail, making re-treatment of these teeth necessary. Using pastes as the sole root canal filling is generally not the treatment of choice. It has many disadvantages, which include the lack of apical length control, inability to obtain a compact obturation, frequent presence of voids and possible severe toxicity if the paste material is extruded beyond the apical foramen. A specific disadvantage of resorcinol paste is the inability to re-treat failed cases because of the hardness of the material once it has set (115). In the event of an overfill into the sinus or the neurovascular bundle, loss of the re-treatment option and the potential for severe irreversible damage makes this choice unreasonable in the year 2009.

Prevention of overfill

Gross overextension of obturation materials usually indicates a faulty technique. However, as long as the overextension is not in contact with fragile structures, such as the inferior alveolar nerve or sinuses, and the apical terminus is well filled in three dimensions, permanent harm is potentially small, unless the obturation materials contain paraformaldehyde.

Techniques for obturation control

There are a number of contributions to the literature that assess techniques for apical control of obturation materials. Tronstad (116) assessed the apical plug of dentin chips in monkeys and showed that a plug of clean dentin filings free of microorganisms could

provide an apical matrix that was well tolerated by the tissues and would provide an apical barrier which would allow the canals to be well sealed and yet protected against impingement of filling materials on the periodontal tissues. In other studies of dentin plugs, the dentin plugs served as an effective means of preventing extrusion with thermoplastic techniques (117, 118).

While there are many reports that this technique promotes healing (116, 119, 120), there are also contradictory findings reporting that a dentin plug appears to inhibit the deposition of cementum and bone when placed at the apical foramen of over-instrumented root canals in monkeys (121).

In a comprehensive study comparing the apical plugs of dentin vs. calcium hydroxide to prevent overfilling, when the apical foramen had been intentionally over-instrumented in cats, the investigators found plugs of calcium hydroxide or dentin to work equally well (119). However, the calcium hydroxide plugs were less durable and produced foramina mineralizations that were less complete than the dentinal plugs. Periapical healing was similar for both calcium hydroxide and dentin. This study was corroborated in ferret canines by Holland (122).

In another study that looked at foramen size as it affected apical extrusion of thermoplasticized gutta-percha, it was noted that overfills and the extrusion of material occurred proportionately to the area of the apical opening. An opening the size of a 40 (0.40 mm) diameter file was found to be twice as likely to allow extrusion of material than an apical diameter sized at 20 (0.20 mm) (123).

When the sealing ability of laterally condensed gutta-percha was compared with injection-molded thermoplasticized gutta-percha in straight and curved canals, only the thermoplasticized technique produced over-extensions (124). It has also been shown that considerable differences in flowability exist between gutta-percha brands when using a thermocompaction technique (125). The recommendation to consider a hybrid technique when using thermoplasticized materials has often involved a cold condensation of gutta-percha apically or a custom-chloroform-dipped master cone, followed by a thermomechanical compaction, providing a safer barrier for limiting the extrusion of material (123, 126, 127). Root filling extrusion was also characterized as being significantly influenced by 'operator' behavior (127).

Clinical case reports involving overfill with heat-softened gutta-percha are increasing in the literature (128, 129). The current practice of maintaining apical patency and the popularity of thermoplastic gutta-percha filling techniques have increased the likelihood that overfills might involve the neurovascular anatomy. Fanibunda et al. (129) warn of the lesser known danger of thermal and mechanical insult from reasonably 'safe' materials being extruded into the inferior alveolar canal. They report a case of thermally compacted gutta-percha having a severe effect on patient sensory loss after gross overfill into the mandibular canal. In this case, they identified a mechanical (compression), chemical (calcium hydroxide sealer) and thermal insult (molten gutta-percha) to the nerve (129).

It is increasingly recommended in the recent literature that sealer overfills into the inferior alveolar nerve need to be assessed immediately for symptoms and removed surgically if IAN damage is suspected (130–132).

In the final analysis, the decision of whether and when to intervene surgically in the removal of any overfill should be based on objective criteria and a comprehensive assessment of each individual patient. The current guidelines for intervention are unfortunately not based on satisfactory evidence-based science, and this leaves a troublesome vacuum in our knowledge of effective therapies, making prevention of an overfill outcome critical to treatment planning before initiating root canal therapy.

Carrier-based gutta-percha

Carrier-based gutta-percha was first introduced as Thermafil™ (Dentsply Tulsa Dental, Tulsa, OK, USA) (133). The Thermafil™ obturator currently consists of a plastic carrier and is covered in a uniform layer of gutta-percha. The carrier is constructed from a special radiopaque plastic similar to a manual or a rotary endodontic instrument. The obturator is heated in a special oven where the gutta-percha it carries assumes a softened state with unique adhesive and flow characteristics. The ideal canal preparation for a carrier-based obturator must allow sufficient space for the flow of cement and gutta-percha (134). Carrier-based obturators use techniques that caution against the use of excess cement because of the increased likelihood of overfilling due to the piston-like effect of the obturator during placement. Because the risk of overfilling is considered the only true limitation of carrier-based

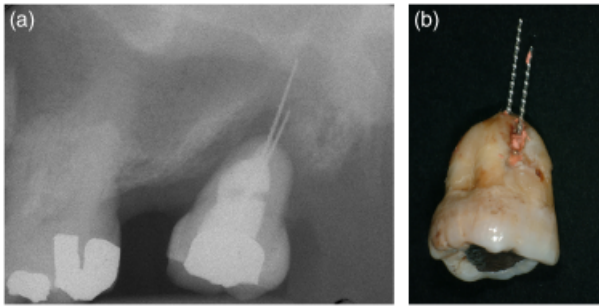


Fig. 9. (a) Overfill of gutta-percha carriers and extreme structural loss in an upper second molar. (b) Extraction demonstrates the apical transportation performed by abusive shaping and the hopeless prognosis. Courtesy of Dr. Karina Roth.

obturators, authors and manufacturers caution against the following major errors in technique:

- incorrect canal preparation including overinstrumentation and laceration of the apical terminus (Figs. 9a and b);
- excessive cement or gutta-percha (135);
- excessive force and velocity during insertion (135); and
- improper obturator selection (134, 135).

Mineral trioxide aggregate as an apical barrier

Clinicians will need to occasionally utilize a technique that promotes the placement of a dense 4–5 mm barrier of mineral trioxide aggregate (MTA) in a canal with severe apical transportation where overfill has a high likelihood (136). MTA has been reported to be an ideal material of choice for root perforations. In fact, this material offers a biological compatibility, demonstrating the growth of a cementum-like substance on the surface of the material (137–140). MTA is cement composed of tricalcium silicate, dicalcium silicate, tricalcium aluminate, tetracalcium aluminoferrite, calcium sulfate and bismuth oxide. This MTA barrier should be confirmed both radiographically and clinically. Fluids present in periradicular tissues external to the canal will provide sufficient moisture for the apical aspect of the positioned MTA to set. In addition, a pre-sized cotton pellet moistened with saline must be placed against the coronalmost aspect of the MTA within the canal. At a subsequent appointment, the MTA cement is probed with a sharp explorer or a large file to determine its hardness. Typically, the material

has set hard and the clinician can then obturate the canal against this barrier.

Prevention and outcomes of obturation overfill

In summary, it is recommended that the clinician observe the following counsel:

- It is critical to use obturation materials that are well tolerated by the body after therapy.
- The clinician must practice careful and judicious shaping strategies that use multiple confirmations of working length and take stringent precautions against overinstrumentation.
- It is important to use a ‘resistance form’ in controlling overfills. This ‘resistance form’ can be imparted during canal preparation by producing funnel-form, tapered preparations and by selecting gutta-percha cones to match those canal shapes that will resist the obturation forces which promote extrusion.
- When using thermoplastic techniques, it is important to respect the flow characteristics of the materials and the heat energy used.
- In cases of extreme proximity to the neurovascular anatomy or the maxillary sinuses, or when the apical constriction has been compromised by instrumentation, the importance of creating a clean dentin plug or other material barrier at the patent apical terminus should be carefully planned when the risk of extrusion is considerable (Figs. 10a and b).

Local factors affecting repair and healing

The conditions impacting the repair of the periradicular complex after overfill include (141):

- systemic and circulatory conditions that impact the blood supply;
- quality of the inflammatory response and infiltrates;
- presence of infection;
- quality of the three-dimensional seal at the terminus; and
- traumatic occlusion.

A period of post-operative observation following root canal therapy ranging from 6 months to 4 years has been advocated by various investigators (142). Teeth that receive endodontic therapy for irreversibly

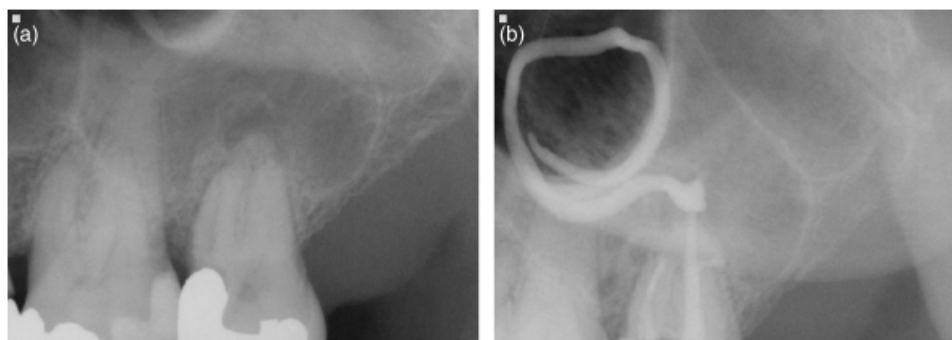


Fig. 10. (a) Upper second molar with apical pathosis in close proximity to the maxillary sinus. (b) An extreme overfill into the sinus resulting from the combination of an over-instrumented apex and an automated thermoplastic technique.

inflamed pulpitis without periradicular infection have higher rates of healing than teeth with necrotic pulps and periradicular infections (143, 144). A majority of healing studies recommend an observation period of no less than 1 year; most prefer at least 2 years, with a recognition that root canals which are initially infected take longer to heal.

There is less agreement about what constitutes true healing when the majority of the literature is considered. Nonetheless, there are key shared characteristics that are universally accepted in all considerations of successful healing, even when overfill is an outcome of treatment:

- an absence of pain and swelling;
- no evidence of on-going tissue destruction;
- a repair of any sinus tracts;
- the tooth is in function; and
- there is radiographic evidence of repair or lessening of the rarefaction between 6 months and 24 months.

The causes for post-treatment disease and/or delayed repair after endodontic therapy have been investigated by many diverse authorities (32, 46, 48, 145). Regardless of how these outcomes are categorized, they are invariably attributed to one or more of the following reasons:

- poor access cavity design and execution;
- an iatrogenic mishap or a procedural error;
- untreated canals or systems (145);
- poorly cleaned or obturated canals (145);
- instrumentation errors such as ledging, perforation, transportation from the center, separated instruments (33, 37–43);
- overextension of obturation materials (146, 147);
- coronal leakage (148, 149);
- extraradicular infections or cysts (150); and

- root fracture (151).

A huge number of studies have been conducted to assess the outcomes of endodontic treatment. Reviewing the classic study by Strindberg (152), we can see that most investigations are clinical follow-up studies on endodontic treatment outcomes (147, 153, 154). Ørstavik examined the time course and development of chronic apical periodontitis in endodontically treated teeth and showed that most cases of apical periodontitis develop within 1 year, while healing proceeds over 4 years (142).

We recognize that knowledge of these outcomes and long-term studies should encourage reflection by the practitioner on the prudent practice of endodontics. Our obligation to protect patients from harm is met when we, as thoughtful clinicians, can provide advanced therapy in a controlled manner with the healing of our patients as the ultimate goal.

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