ENDODONTIC TREATMENT: THE PREREQUISITE FOR THE PLACEMENT OF FIBER POSTS

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The study and practice of Endodontics includes basic clinical science comprising the biology of healthy pulp, and the etiology, diagnosis, prevention and treatment of diseases and injuries of the pulp and associated periradicular conditions.[1]

Until the middle of the 19th century, endodontics did not play a significant role in dental therapeutics, as there was no prevention, no scientifically tested materials, no standardized and reliable clinical protocols. During this era, endodontic treatment was performed on a trial and error basis, with little chance of predicting clinical outcomes. However, during the last 50 years, a whole generation of dentists has become committed to this field of dentistry, with the ultimate realization of endodontics as a clinical speciality.

The innovations in restorative dentistry over the past decade have contributed significantly to improving the quality of the restorations of root-treated teeth, giving them a better long term prognosis. Microbiologic studies have demonstrated that controlling pulpal infection is of utmost importance for successful endodontic treatment, and directed the therapy to a rational approach no longer founded on an empirical but on a scientific basis.

The introduction of new materials and instruments for the preparation, cleaning, shaping and obturation of the root canals has contributed to the dissemination of endodontic practice among general dentists. While this has allowed clinicians to restore teeth that previously would have been extracted, it has clearly demonstrated the limits of contemporary endodontics. Like every discipline, endodontics has guidelines and clinical protocols, which every dentist should carefully follow to achieve success and reduce the number of failures.

Pre-Endodontic Restoration

The success of endodontic therapy depends on the correct cleaning, shaping and filling of the root canals,[2] but before starting these procedures, the tooth must be isolated with the use of rubber dam and the cavity access prepared. These first two steps of the therapy are of particular importance and should not be under-estimated nor carried out superficially, as an error at this stage could compromise the rest of the treatment.

If the tooth cannot be isolated, neither the endodontic nor the restorative treatment can be performed. Apart from a situation where the tooth is in such a poor state that extraction is the only possible solution, there are cases where the isolation of a tooth may be difficult. In endodontics, the pre-treatment phase may be defined as a set of techniques which prepare the tooth for endodontic treatment and which allows and/or simplifies an optimal isolation of the operative field.[3]

Root canal treatment, therefore, does not begin with the placing of the rubber dam, but rather with all the periodontal and restorative procedures necessary to simplify its placement. In any endodontic treatment, it is of fundamental importance to have a sterile operative field. Once the dam is in position, the clamp and the tooth must be disinfected with cotton wool soaked with a fast- evaporating antiseptic.[4]

There are several disinfectants and techniques which can be used to remove contaminated bacteria from treated surfaces, with simple and standardized protocols being suggested by some authors. Dental plaque should be removed with rubber points and prophylactic pastes prior to the placement of the rubber dam after which the operative field should be cleaned initially with 30% hydrogen peroxide and subsequently with an iodine-based disinfectant.[5,6]

The pre-treatment procedures which are used to prepare a tooth for endodontic treatment may be divided into two types according to their duration: provisional pre-treatment types and semi-definitive pre-treatment types. The former are self-explanatory and have a limited time duration, whereas the latter may be used even after the conclusion of endodontic therapy. From a clinical point of view, however, pre-treatment procedures are separated into periodontal procedures and restorative procedures. Not included in these descriptions are

Figure 1: Examples of different methods of isolation of the operative field.

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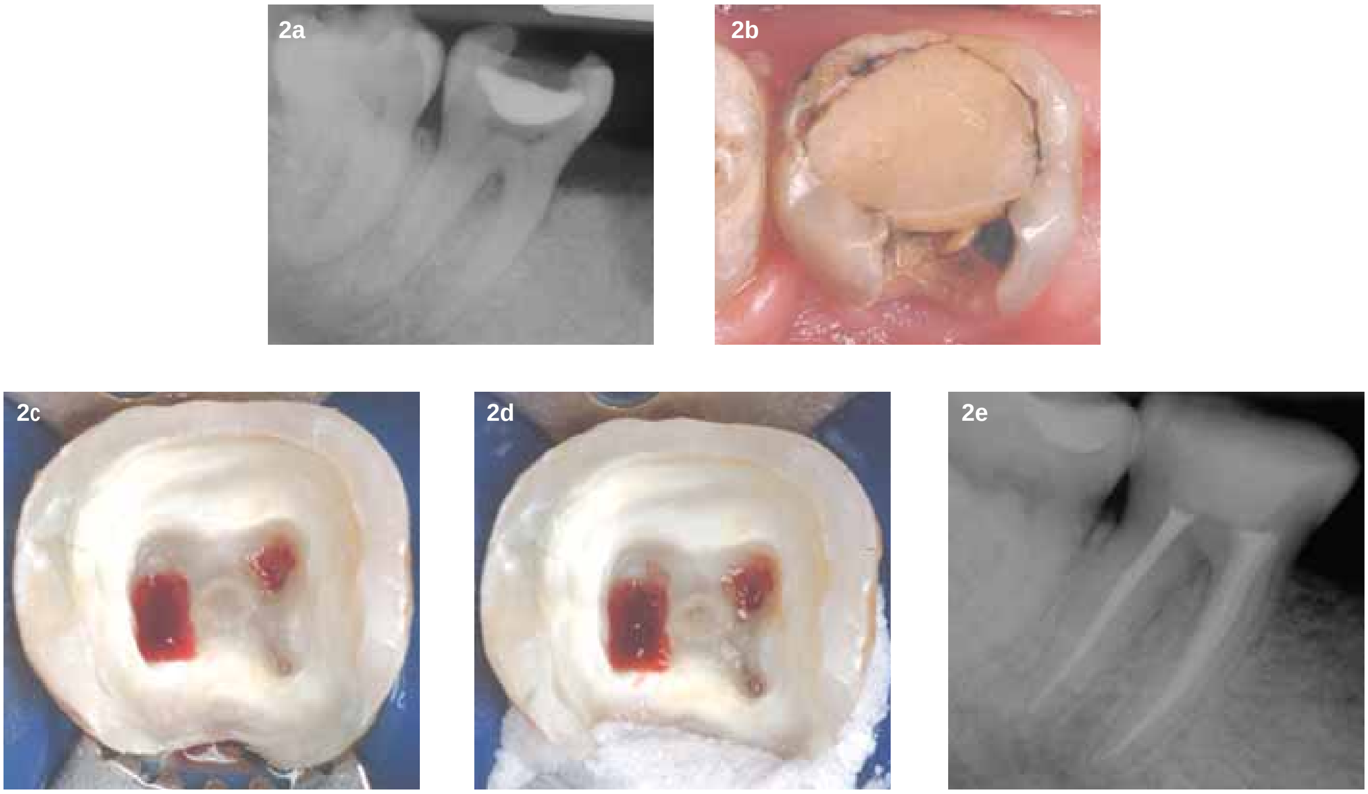


Figure 2: Example of pretreatment; 2a: diagnostic x-ray; 2b: clinical situation; 2c: after initial opening of the pulp chamber, and use of the rubber dam, the buccal side still needs further isolation; 2d: isolation completed with the help of fluid silicon (OpalDam, Manufact, Country); 2e: 1 yr post-op control.

clinical cases in which the prevailing periodontal conditions must be first addressed before endodontic therapy can commence. However, should clinicians find themselves working under emergency conditions and are thus unable to request that the patient undergoes periodontal treatment, they should still eliminate any plaque or calculus near the access cavity.

Teeth requiring endodontic treatment seldom have the anatomy which is suitable for treatment "lege artis". Reductions in the height of clinical crowns due to anatomical or pathological reasons may render the application of the rubber dam difficult. However, if the operative field is inadequately isolated this could jeopardize the optimal seal that is required to prevent re-infection of the root canal space in the time between appointments.

It has been suggested that the stabilization of the clamp in order to position the rubber dam is the crucial moment for deciding whether or not to carry out endodontic pretreatment.[7] There are cases which appear difficult but which may be solved with methods which do not change the dental structure. The use of a rubber dam clamp which has not been designed for that specific purpose may be a viable alternative, such as using a clamp made for incisors for premolars or even molars (Figure 1). On other occasions, it may be sufficient to modify the conformation of the clamp to adapt it to a tooth with poor crown structure. For example, the clinician may tilt the top of the points that anchor the clamp to the tooth.[6] Alternatively, the clamp may be stabilized by using a composite with adhesive properties.[8]

Once the clamp has been stabilized, any gap between the rubber dam and the crown of the tooth should be eliminated even if one or more of the tooth walls are missing or if there has been pre-endodontic restoration. Common dental materials such as zinc oxide-eugenol cement, resins, or polyvinylsiloxane impression materials may be used for this purpose.[9,10] There are also "fluid dams" available that are designed to prevent the infiltration of saliva, blood or irrigation fluid into the operative field.

Walton and Torabinejad suggest that the best preparation for cavity access is to section the tooth at the cervical level, as this gives full visibility and allows for the most direct access as the pulp chamber is completely exposed.[6] Although the authors indicated that any restorative pre-treatment would compromise subsequent endodontic procedures, there are clinical cases where restorative pre-treatment is mandatory (Figure 2).

The aim of restorative techniques of endodontic pre-treatment is to restore the previously mutilated dental anatomy to a state that makes endodontic therapy easier and gives better post-endodontic coronal seals. Different restorative materials may be used, including reinforced zinc oxide-eugenol cements, glass-ionomer cements, and both auto- and light-cured resin composites. It should be pointed out that pre-endodontic restorations with resin composites may be re-used as the foundation for subsequent post-endodontic restorations. Mechanical devices such as copper bands and orthodontic bands are used less frequently than in the past due to the difficulties encountered in trying to ensure a hygienic environment as well as the periodontal problems these accessories may cause. Other studies suggest that the cusp tips of posterior teeth should be completely removed in more complex cases as this eliminates crown interference, avoids tooth fracture during treatment, and provides constant and precise reference points during obturation of the root canals.[12]

In general, an optimal pre-treatment method is based on the ease and economy of time and work with which a procedure is completed. However, when pre-treatment is indicated, it should not be seen as a laborious task by the clinicians, but rather an effort on their part to ensure success, reduce failures, and avoid discomfort for the patient.

Access Cavity

The access cavity is the first step in root canal preparation and a fundamental stage in its treatment. This consists of forming an access path in the crown of the tooth, which is of a well defined form, size and position. Not only does this allow the dentist to locate the root canals, but also permits proper cleaning, shaping and obturation.

The importance of access cavity preparation is often underestimated. In reality, the prognosis of root canal treatment is directly linked to the accuracy and care taken when initially accessing the root canal system. Should the access cavity be improperly prepared in position, depth, or width, the root canal treatment becomes unpredictable.

The instruments used for preparing the access cavity include:

- Diamond burs (e.g. Intensive 206, 314S, 117M) for the penetration phase;
- Zekrya-Endo Maillefer bur, for the finishing phase;
- Contra-angle handpiece round burs (28mm) N° 010, 014, 016;
- Contra-angle handpiece round bur Maillefer LN 205-006;
- Explorative root canal investigation probe (Hu-Friedy DG16)

Preparation of the access cavity may be schematically divided into 3 stages: penetration, enlargement and finishing. Penetration is carried out using a diamond bur of various shapes depending on the anatomy and type of the tooth. Once the pulp chamber has been opened, the chamber walls are extended and finished. If the pulp chamber has calcified or if the roof is close to the pulpal floor, then enlargement of the

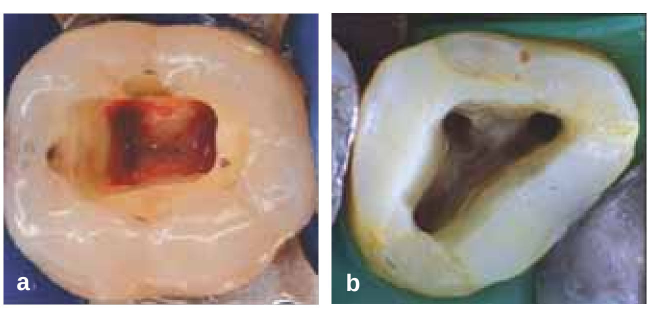


Figure 3: access cavities in lower (3a) and upper molars (3b).

Figure 4: Access cavity in molars with unusual shape and size

pulp chamber may be achieved by using a rosette bur of various diameters or an ultrasonic tip. This enlargement procedure is performed only if required, and with limited tissue removal.

In contrast to restorative dentistry where the cavity outline form depends on the size of the carious lesion, the access cavity form in root canal therapy is dictated by the shape of the pulp chamber and the number of canal orifices (Figure 3).[12,13] The factors which regulate this are the size and shape of the pulp and the number, direction and curvature of the root canals. The outline form is often modified during the preparation of the coronal third of the root canal to enable straight line access into the root canals (Figure 4). Initial access is achieved along the occlusal or lingual surface of the tooth. The roof of the pulp chamber is removed and all organic matter eliminated. This facilitates cleaning of all the coronal pulp (including pulpal horns) and avoids potential problems such as crown discoloration or re-infection of the filled root canal space. If the access preparation is correctly performed, the pulpal floor and the canal orifices should be clearly visible without perforating the furcation area.

It is important that the access cavity facilitates the use of the instruments in the root canals and provides unrestricted access to the apical third of the root canals. This ensures enough space for the endodontic instruments to work freely in the canals without interference from the coronal portion of the cavity. The access cavity must therefore be extended in the opposite direction to the root thus eliminating any interference that may block direct access by the instruments.

Failure to eliminate crown interference may result in incomplete cleaning of the canal system, and an increased risk of creating ledges, perforations, stripping and transportation of the apical foramen. However, excessive enlargement of an access cavity to the extent of destroying a cusp should be avoided from a restorative perspective. With the advent of contemporary ultrasonic devices and long shank burs with smaller heads, it is possible to remove dentin selectively while preserving sound dentin structure for post-endodontic rehabilitation.

The access cavity should also provide stable support to the provisional restoration and preferably, should have four walls. This is especially important when there has been a loss of a large amount of tooth structure due to caries or if the root canal treatment has to be completed over several

Table I. The most important elements of endodontic treatment
Removal of vital and necrotic tissue from the main root canal(s)
Creation of sufficient space for irrigation and medication
Preservation of the integrity and location of the apical canal anatomy
Avoidance of iatrogenic damage to the canal system and root structure
Facilitation of canal filling
Avoidance of further irritation and/or infection of the periradicular tissues
Preservation of sound root dentine to allow long-term function of the tooth

appointments. It is important to have considerable knowledge of the anatomy of the tooth before attempting to prepare the access cavity, particularly when a tooth is tilted due to the extraction of an adjacent tooth. Careful clinical examination of the tooth inclination and good pre-operative x-rays at different angulations will help to avoid unnecessary errors.

Root Canal Preparation

The major goals of root canal preparation are the prevention of periradicular disease and promotion of healing in cases where disease already exists. Root canal preparation is undoubtedly the most delicate and complex part of the whole treatment, as illustrated by the statement that "what comes out of the canal is much more important than what goes into it".[14] In 1974, Schilder outlined the most important elements of endodontic treatment (Table I), and established that proper cleaning and shaping of the root canal is the basis for successful treatment,[15,16]. Cleaning and shaping are usually performed simultaneously using instruments and irrigants. Schilder [14-16] also described the following five design objectives:

I. A continuously tapering funnel from the apex to the access cavity;

II. The cross-sectional diameter should be narrower at every point apically;

III. The root canal preparation should follow the shape of the original canal;

IV. The apical foramen should remain in its original position;

V. The apical opening should be kept as small as practical.

and the following four biological objectives:

I. Confinement of instrumentation to the roots themselves;

II. No forcing of necrotic debris beyond the foramen;.

III. Removal of all tissue from the root canal space;

IV. Creation of sufficient space for intra-canal medicaments.

To satisfy the aforementioned objectives, irrespective of the preparation technique adopted, the dentist must have a comprehensive knowledge of the root canal anatomy, the instruments must be used strictly according to their features, and standardized filling procedures should be followed. Over the last decade, numerous studies have been published on both manual and mechanical root canal preparation and although traditional stainless steel instruments have been in use for almost a century, the most suitable technique has not yet been established.

Manual Root Canal Preparation

For many years, the step-back technique[15] was the one most commonly employed, using 0.02 tapered stainless steel manual instruments, to obtain root canal preparation with a progressively funneled shape. The technique utilizes a "apico-coronal" approach; i.e. the first instrument has to reach the apex and subsequent canal preparation commences from the apical third. For this reason smaller instruments are used initially and then replaced by larger instruments to obtain a conical shape. Finally, Gates-Glidden drills are used to shape and enlarge the coronal third to complete the desired canal shape.

Frequently, root canals requiring endodontic treatment have lost their natural conical shape through caries, preceding therapies, traumas and are either calcified or partially occluded with filling materials. The first instrument used in the root canal is thus often blocked before reaching the apex. Forcing these instruments can easily create ledges, stripping or separation of the instrument. Although Schilder[15] was the first to recognize the importance of removing coronal interferences in order to more effectively shape the apical third of root canals, the technique of "crown-down" preparation is often attributed to the studies reported by other authors.[17-20] These authors confirmed the concepts introduced by Schilder regarding the funnel-shape preparation, but performed the shaping procedure in the opposite direction, from the crown to the apex. Laurichesse et al. in 1971 [17] and Riitano in 1976 [18] proposed the preparation of the apical third of a root canal only after the preparation of the middle and coronal third. In this way, the instruments are free to reach the apical third and are not forced towards the root canal walls, hence avoiding iatrogenic damage. Moreover, the preparation of the apical third as a final step is more logical, as preparation of the most delicate and hazardous area of the root canal occurs in the final stages where there is better access after the flaring of the coronal and middle thirds of the root canals.

In 1980, Abou-Rass at al.[19] introduced the anti-curvature filling method, which requires the removal of an adequate quantity of dentin on the external area of the curvature in the coronal third, avoiding the danger zones close to furcations. In the same year, Morgan and Montgomery[20] described a new technique with a crown to the apex approach called the "crown-down pressureless technique". This requires an early coronal enlargement using Gates-Glidden drills and subsequently using files with an inverted sequence, from the largest to the smallest, in a rotary movement. In 1982, Goering et al. [21] proposed another technique known as the "step-down" technique. This is similar to the aforementioned technique (early coronal enlargement or preflaring) using

Hedstrom files and Gates-Glidden drills, but using the instruments from the smallest to the largest.

The "balanced force technique" was introduced by Roane et al. in 1985.[22] The technique was originally associated with the use of specially designed stainless-steel or nickel-titanium (NiTi) K-type instruments (Flex-R-Files) with modified tips in a step-down manner. The instruments are introduced into the root canal with a clockwise motion of a maximum of 180 degrees and apical advancement (placement phase), followed by a counterclockwise rotation of a maximum of 120 degrees with adequate apical pressure (cutting phase). The final removal phase is then performed with a clockwise rotation and withdrawal of the file from the root canal. Apical preparation should be larger than that recommended for other manual techniques, e.g., to size #80 in straight canals and size #45 in curved canals. The major advantages of the "balanced force technique" are: 1) good apical control of the file tip as the instrument does not cut over the complete length; 2) optimal centering of the instrument because of the non-cutting safety tip; and 3) eliminating the need to pre-curve the instrument.

In 1993, Scianamblo et al. [23] described another root canal preparation procedure that is based on the aforementioned techniques, and stressed the concept of early coronal enlargement. Following pre-enlargement, the apical third is negotiated last, establishing patency, and confirming working length. The apical zone is then finished so that a smooth uniform taper from the orifice level to the radiographic terminus is obtained. The disadvantage of this procedure is the large amount of time required, the large number of instruments used, and the risk, with Gates-Glidden drills, to provoke stripping at the middle and coronal level.

Many studies have shown that pre-enlargment (preflaring) of root canals has several advantages.[22,24] Firstly, preflaring removes the bulk of the necrotic and infected tissues from an infected root canal prior to apical instrumentation. The technique also increases the tactile sensibility and control of the instrument tip in the most difficult working area of the root canal. Enlargement of the apical third may then be carried out without forcing the instruments, thus avoiding iatrogenic damages such as displacement or blockage of the apical foramina. Finally, preflaring allows a greater penetration of the irrigants, and less extrusion of debris into the periapical regions [25-28]

Canal Preparation with Rotary Ni-Ti Instruments

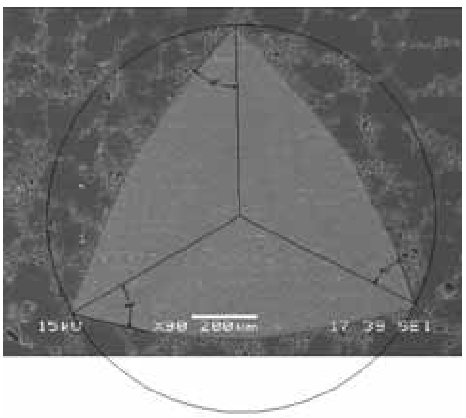
With the advent of the Ni-Ti alloy,[29] endodontists have the option of using a more pliable material that can follow the canal curvature more easily. Ni-Ti is composed of approximately 55% nickel and 45% titanium, and has a variable formula. It has the ability to alter its type of atomic bonding, generating unique changes in the metallurgical properties and crystallographic arrangement of the alloy. These changes depend on temperature and stress, which can induce the transition of the alloy from an austenitic phase (more stable) to a martensitic phase (more dynamic). The two main features of the alloy are shape memory and super-elasticity.[30] The elasticity of Ni-Ti instruments in bending and torsion is two to three times higher than that of stainless steel instruments. The modulus of elasticity is significantly lower for Ni-Ti alloys than for stainless steel. As a result, lower forces are exerted on intraradicular dentin when compared to stainless steel instruments.[31] In order to take advantage of these features, Ni-Ti instruments should be kept active, through constant and continuous rotation within the root canal. Kazemi et al. demonstrated that Ni-Ti instruments require less force to bend and can sustain a greater strain than those made of stainless steel before surpassing the elasticity limit and fracturing.[32]

Because of the metallurgical properties of Ni-Ti, it was possible to engineer instruments with tapers greater than 2%, which is the norm for stainless steel instruments, as well as reduce the lateral forces during instrumentation. Greater taper instruments are well-suited to the "crown-down" technique. During treatment, the part of the instruments with the greater taper makes contact with the coronal third of the root canal and enlarges it, eliminating any interference at this level. This subsequently allows access to the apical third of the root canal by instruments with reduced tapers. In this way a reduced lateral force is applied on the curved canal walls during instrumentation, decreasing the number of canal damages when compared with the results obtained using traditional stainless steel instruments.[31] Recent studies have shown that Ni-Ti instruments: a) reduce the number of zips, ledges and apical transportations; b) remain more centered in the apical lumen; c) remove less dentin, d) produce rounder preparations; and e) are faster in shaping the root canal walls.[33-36]

Many Ni-Ti instruments are commercially available and their manufacturers claim greater safety and easier instrumentation than with stainless steel instruments. Although Ni-Ti instruments vary considerably in their design,[31] the blades may be classified in two main categories: active cutting angles or radial planes (rake angle). The former allows a cutting action and a faster progression of the instruments than the latter, which works with a smoothing action rather than with a real cutting action. The instruments also vary considerably according to their transversal section. By reducing the area of contact with the root canal walls, the cutting action is more efficient and torsional stress is reduced.[31] The core of the instrument influences its flexibility and its mechanical properties. When the core is reduced in dimension, the instrument has a greater flexibility which respects the root canal anatomy.[31] A deep groove allows more debris transportation, increasing its cleaning effectiveness. Cutting efficiency and flexibility may also be regulated by balancing the flute angle. The greater the flute angle, the greater the flexibility. Regarding the instrument tip, most of the recently marketed Ni-Ti instruments have a non-cutting or safe-cutting tip design, thus reducing the possibility of altering the root canal anatomy (Figure 5).

Practical Advice when using Ni-Ti Instruments

Although the flexibility of Ni-Ti instruments is greater than that of stainless steel instruments, fracture (separation) is still a risk and often occurs insidiously.[37] In the majority of clinical situations, instrument separation occurs in the apical third of the root canal, rendering the fractured portion very difficult to remove. There are two main reasons for the separation of these instruments: torsion fractures and cyclic fatigue fractures.[38] The former occurs when the tip of the instruments is blocked in the root canal yet the shaft continues to rotate, exceeding the elasticity of the alloy. This kind of fracture is often due to an excessive force applied to the instruments by the dentist.[39] However, cyclic fatigue is the most common reason for the separation of Ni-Ti instruments.[40] As an instrument rotates inside a canal, it undergoes alternate shifts from compression to tension during each rotation cycle, thus creating fatigue stress along the instrument surface. The result



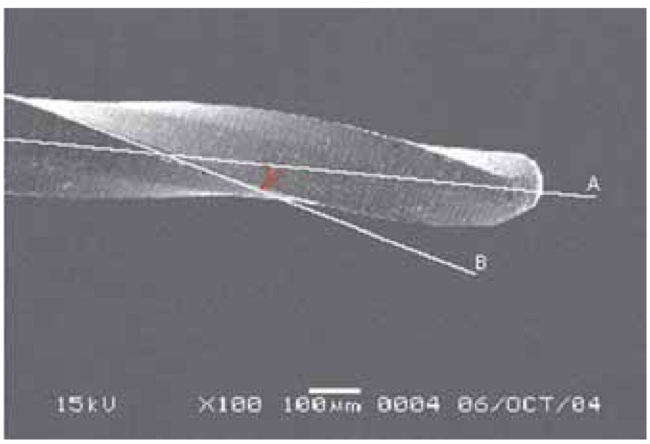


Figure 5a: (Rake angles) Calculation of rake angles using a SEM of the cross-section of a ProTaper instrument. The rake angle is the angle between the cutting edge of the instrument and a plane perpendicular to the working surface to which the instrument is applied.
Figure 5b: (Flute angles) Calculation of flute angles using a SEM of a ProTaper instrument. The flute angle is the angle between the flute orientation and the long axis of the instrument.

Table II.

SYSTEM	Speed (rpm)
Profile (Dentsply-Maillefer)	150-350
GT Rotary (Dentsply-Maillefer)	150-350
Protaper (Dentsply-Maillefer)	250-350
HERO 642 (Micromega)	300-600
HERO Shaper (Micromega)	300-350
Flexmaster (VDW)	280-300
K3 (SybronEndo)	300
MTwo (Sweden & Martina)	< 350
Lightspeed (LSX)	750-2000

of this cyclic stress is not usually visible to the naked eye. However, evidence of microcrack formation may be observed when used instruments are examined with scanning electron microscopy. These microcracks represent surface flaws that are generated during the manufacture of the instruments or slip-planes that are generated after clinical use of the instruments. Crack initiation stress along these regions may be further increased by dentin chip embedding and wedging. Once these cracks are initiated, they propagate progressively during each rotation cycle, creating heavy stress concentrations that rapidly spread inward and eventually result in damage along the center of the instrument shafts. To minimize instrument separation via cyclic fatigue, several important issues must be borne in mind regarding the use of rotary Ni-Ti instruments. This includes limiting the re-use of these instruments, using low-speed, low-torque motors, having pre-operative knowledge of the root canal curvature, inserting the instruments along the correct entry axis (i.e. straight line access), and limiting the length of time in which an instrument is allowed to rotate within the canal. Some practical suggestions are included below to reduce the risk of instrument separation.

Using the correct speed

To optimize the superelasticity of the Ni-Ti alloy, rotation of an instrument should be continuous and kept at a constant speed. The rotation velocity varies according to the system used. As each manufacturer recommends a range of speed within which the instrument should be used (Table II), it is advisable to follow these instructions closely. The higher the speed, the better the cutting efficiency - however, this is achieved at the expense of increasing the torsional stress on the instruments. If the speed is incorrect, together with an inappropriate torque, rotation can be discontinuous. This decreases the efficacy of the instrument in removing debris which subsequently remains between the blades and can cause instrument separation.

Rotation and apical progression of the instrument must be continuous. Forcing the instrument toward the apex should be avoided in situations such as calcified and narrow canals where the cutting blades are heavily stressed, and progression to the apex is difficult. The problem causing this should be investigated. A push-pull motion should then be used instead, pulling the instrument up and then reinserting it. Ideally, the instrument should not touch the canal walls for more than 3 mm and should not rest in the same position for more than a few seconds. The clinician should avoid bringing the instrument to the same length more than once while trying to progress to the apex. When obstacles are present in the canal (ledges, zips, separated instruments, false paths, sharp curves), it is advisable to reach the working length initially with traditional stainless steel hand instruments prior to the use of rotary Ni-Ti instruments.

Irrigation and lubrication

Ni-Ti instruments generally have a blade design which allows them to carry debris more easily to the surface. However, according to some scanning electron microscopy studies, these files produce a thicker smear layer, particularly in the apical third of the root canal walls.[41] It is therefore advisable to use a lubricant in the initial preparation stages, not only to reduce the accumulation of the debris, but also to reduce friction and torsional stress. Furthermore, even if using Ni-Ti files allows the clinician to reduce the amount of time spent on the preparation, the irrigant should be left to act inside the root canal for the required amount of time.

Avoiding excessive pressure

The instrument should be inserted into the canal with a "push-pull" movement, and a light and gentle touch. Theoretically progression to the apex should be achieved one millimeter at a time, applying a constant pressure and without forcing the instruments.

Using and not abusing the instrument

Although many clinical and research studies have been carried out, they have not been able to give a definitive answer on the number of times an instrument may be re-used before its deterioration warrants its disposal (Figure 6). Some authors suggest it should be discarded after each use,[42] while others maintain that deterioration is caused not only by the number of times it has been used, but is rather an accumulation of several factors such as the instrument design and the anatomy of the root canals.[43] Sterilization has also been suggested as one of the possible causes of instrument separation. However, a study demonstrated that dry heat and contact with sodium

Figure 6: Deteriorated instrument. If used again, separation is likely to occur.

Figure 7: Upper molar before and after root canal treatment, insertion of a fiber post and porcelain fused to metal restoration.

Figure 8: Root canal treatment and restorative procedure on a second upper molar.

hypochlorite do not diminish the number of rotations prior to the separation of these instruments via cyclic fatigue.[44] It is very difficult to quantify the amount of stress each instrument undergoes during its use. However, some authors agree that an instrument should not be used for more than ten canals in standard situations. This number is reduced to one in complex cases where calcified canals or sharp curves are present. It is therefore very important to take note of how often the instrument has been used and the type of root canal in which it was used.

In order to keep instrument separation to a minimum, the root canal anatomy should be accurately evaluated before the commencement of root canal treatment. It is always advisable to start the preparation of the root canal (negotiation and pre-enlargement) using hand instruments, and only employ Ni-Ti instruments for the final shaping of the root canal walls. Furthermore, before storing the instruments after sterilization, the number of times the instrument was used should be recorded on the box so that this information is immediately available.

Operator skills

Finally the skills and experience of the dentist are crucial factors in the correct use of rotary Ni-Ti instruments.[45-47] Like any other instrument or technique, mastering the art of Ni-Ti rotary instrumentation requires time and practice. On the acquisition of a new type of rotary Ni-Ti instrument, it is imperative that clinicians test it on extracted teeth prior to using it clinically (Figures 7,8).

Endodontic Irrigants

Cleaning and shaping of the root canal is the combined result of mechanical cleansing of the root canal walls, and the dissolution of debris, removal of endodontic smear layers and sterilization of the instrumented canals.[14,15] Complete removal of debris cannot be achieved by mechanical instrumentation alone. Irrigation is used as a "physical" flush that removes debris, and also serves as a bactericidal agent, tissue solvent, and lubricant.[48-56] Many authors are of the opinion that the mechanical action of flushing an endodontic irrigation solution from the root canal results in a significant reduction of the bacterial flora inside the canal.[49-51] Several studies have shown that the inclusion of a chemical agent as a supplement to the mechanical action makes the irrigant more effective in eliminating bacteria.[48-56] The antibacterial effectiveness of irrigants is evaluated using a sterile saline solution as the control. In an in vivo study on 40 teeth, Kuruvilla and Kamath demonstrated that 0.9% saline solution reduced the CFU/ml (CFU - colony forming unit) by 25%, while chemical irrigants are more than 60% effective.[54] In an in vitro study on 30 mandibular premolars with pulpal pathology, Siqueira and co-workers found that using a saline solution as an irrigant reduced the bacterial cells by 38.3% whereas 2.5% sodium hypochlorite was effective in reducing the bacterial flora by 60%.[55]

The efficacy of an endodontic irrigant also depends on its capacity to reach un-instrumented areas. For this reason, tensioactive substances have been included in the irrigant in order to improve its penetration along the root canal walls. However, to facilitate the penetration of the irrigant, the root canal walls must be properly instrumented. With the use of the "crown-down" technique, early coronal flaring facilitates the penetration of the irrigant. Moreover, Ram demonstrated that an irrigant can only reach the apex if the canal has been enlarged to a dimension greater than ISO size 40.[57] Ideally, an endodontic irrigant should have a potent bactericidal effect but exhibit minimal cytotoxicity on the periapical tissues. However, Spånberg et al. demonstrated, with in vivo and in vitro studies, that no irrigant is able to combine all of these characteristics.[58] All antimicrobial agents have potential toxicity that could eliminate the potential advantages derived from using these agents at higher concentrations.

An ideal irrigant should have the following characteristics:

- Bactericidal, to reduce the quantity of bacteria in an infected canal system;
- Solvent action, by means of proteolytic digestion and dissolution of the necrotic tissues.
- Ease of removal of dentinal debris, by maintaining them in suspension.
- Biocompatibility, in particular the irrigant should not be toxic or irritating to the periapical tissues should it flow out of the apex.
- Lubricating action, to facilitate the use of endodontic instruments, particularly in narrow canals, and consequently reducing the risk of instrument separation.
- Low surface tension, to reach the apical delta and all of the areas which are not accessible to instrumentation.
- No detrimental effect on subsequent filling of the root canal case by endodontic filling materials and root canal sealers
- Possess substantivity by binding to root dentin to maintain its bactericidal action
- Be relatively innocuous for the patient and for the clinician.
- Be easily acquired and have a low cost.

Table III. Irrigants commonly used in endodontics

Saline
Sodium hypochlorite
Chlorhexidine digluconate
Iodophors
Hydrogen peroxide
Citric acid
Phenolic compounds
Quaternary ammonium compounds
Alcohols

Of the commonly used endodontic irrigants (Table III), sodium hypochlorite has been the most thoroughly investigated. Its most desirable characteristic is undoubtedly its wide spectrum anti-bacterial activity and anti-viral effect. Direct contact with it eliminates bacteria, spores, fungi, protozoa and viruses (including HIV, HSV-1, HSV-2, HBV and HAV).[48,55,59] It also has a solvent action on organic tissues, is easily acquired, has a low cost, and has a slight bleaching effect on dentin. Unfortunately, it can have a potential cytotoxic effect on the vital tissues, except for keratinized epithelia.[59] It does not completely dissolve the smear layer, has an unpleasant smell and taste, and can cause allergic reactions.[50,59] Household bleach, which is commercially available o the general public, contains 5.25% sodium hypochlorite. The solution may be used clinically at this concentration or diluted with distilled water to a concentration as low as 0.5%. However, it is still controversial whether the solution should be used in its diluted form, and whether it should be used in combination with other irrigants.[53,54] Spånberg et al. found that 5.25% sodium hypochlorite is stronger than necessary and is toxic for the patient, and suggested using it at 1% concentration. Conversely, other authors have demonstrated that diluting NaOCl diminishes the antimicrobial properties and increases the time required to destroy Enterococcus faecalis. [48,51,60-62] Others suggested the use of 2.5-3% sodium hypochlorite as an endodontic irrigant.[62,63] Mechanisms to increase the effectiveness of sodium hypochlorite include; increasing the temperature, applying frequently, increasing contact time, using ultrasonic energy, combining with chelating agents and other irrigants, adding tensioactive solutions and reducing pH (buffered solutions).

As sodium hypochlorite removes only the organic phase of the smear layer, alternating the use of sodium hypochlorite with irrigants that have the capacity to remove the inorganic phase of the smear layer, is a well-accepted irrigation strategy in clinical endodontics. To date, ethylenediamine tetraactetic acid (EDTA) is commonly used in association with sodium hypochlorite to remove endodontic smear layers that are created during shaping of the root canals.[64-66] Morphologic studies have been extensively performed to evaluate the efficacy of smear layer removal after endodontic instrumentation and irrigation of the root canal.[67,68] Recently, a new chelating agent containing doxycycline hyclate, citric acid and a tensioactive agent (BioPure MTAD, Dentsply Tulsa Dental, Tulsa OK, USA) has been introduced for the disinfection of root canals and removal of endodontic smear layers.[69] This irrigant is recommended to be used with 1.3% sodium hypochlorite.

Root Canal Filling

Over the years, many materials and techniques have been developed to fill prepared canals. Irrespective of the material chosen for the root canal filling, proceeding to the obturation step can only occur once the cleaning and shaping of the canal have been completed. Theoretically, a cleaned and shaped canal is not required to be filled for apical periodontitis to heal.[70] The objective of a root canal filling, irrespective of the technique or material employed, is to generate a fluid tight seal that allows the root canal to be retained in the same aseptic conditions as it was in the cleaning and shaping stage. Current literature supports the importance of a secondary coronal seal to prevent subsequent leakage through filled root canals.[71] Different materials have been proposed for the obturation of the root canal system. Despite a recent challenge as a 150-year old material that represents the end of an era, gutta-percha remains to be the most time-tested and reliable root canal filling on the market, as it possesses most of the characteristics of an ideal material.[72-77]

Gutta-percha is a trans-1,4-polyisoprene based polymer derived from the juice extracts of Palaquium gutta trees. It is easily sterilized, relatively inert and well tolerated by the soft tissues, although overextension of this material in the periapex should be avoided. Due to its thermoplastic nature, it adapts well to the root canal walls with the use of root canal sealers and once these materials harden, they are relatively stable dimensionally. Although gutta-percha is insoluble in organic fluids, it is easily removed when dissolved in a solvent such as chloroform, eucalyptol, or essence of turpentine.

Dental gutta-percha is commercially available in standardized and non-standardized points, pellets or as a component in core-carrier systems. Only 20% of the endodontic composition is gutta-percha with 60 - 75% being zinc oxide fillers. The

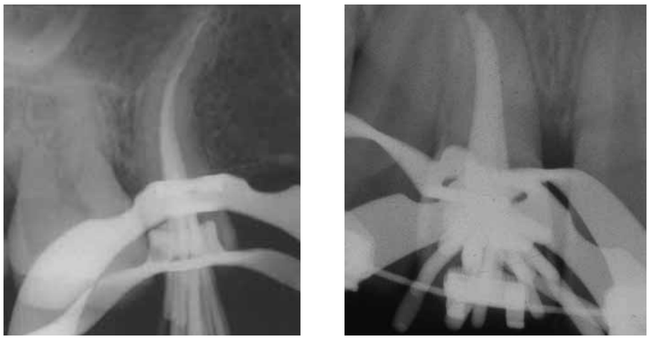


Figure 9: examples of cold lateral compaction.

remaining constituents are wax or resin to render the material more pliable and/or compactable, and metal salts such as barium sulphate to render it radiopaque. There is evidence of slight antibacterial activity from gutta-percha, although it is too weak to be considered as an effective antimicrobial agent.

Chemically, pure gutta-percha exists in two different crystalline forms (alpha and beta) that can be converted into each other. Gutta-percha in the alpha phase has a fusion temperature of about 70°C and horizontally aligned molecular chains. The property gives it good flowing qualities when heated, but a certain rigidity at environmental temperatures. Gutta-percha in the beta phase has a fusion temperature of approximately 60°C and randomly aligned molecular chains which gives it less flowing qualities but more elasticity than the a-gutta-percha making it more suitable for cold compaction techniques. Recent studies have shown that new generations of dental gutta-percha, often identified as a-gutta-percha, are in reality all b-gutta-percha; these different properties depend on a breakage of the polycarbon chains, leading to a decrease in the molecular weight.

From a practical point of view, as all new gutta-percha compounds (except for points and Obtura) are high flow and adhesive gutta-percha, it is not necessary to assert a lot of pressure to adapt these to the root canal walls. However, the effect of heating on the volumetric change of gutta-percha is most important to dentistry. These materials expand slightly upon heating (which is desirable for an endodontic filling material), giving the clinician an increased volume of material that may be compacted into a root canal cavity. Unfortunately they also shrink on cooling, losing some of their adhesive properties. It is therefore recommended to use small doses of an endodontic cement.

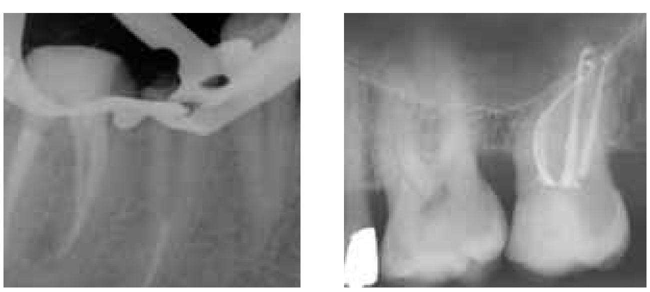


Figure 10: examples of warm vertical compaction.

A frequent clinical question is: when should one complete the obturation of the root canal? Should it be done at the end of the cleaning and shaping stage, or postponed to a future appointment? This is sometimes a complex decision and depends on the following factors. Firstly, operative difficulties, such as difficult anatomy, time constraints, complex cases. Secondly, the presence of exudates, after the drying stage of the root canal, obliges the dentist to postpone the obturation stage. Finally, if the tooth is still sensitive, it is advisable to postpone the completion of the treatment.

The methods for the obturation of the root canal vary according to the direction of the compaction (lateral or vertical) and/or the temperature of the gutta-percha (cold or warm). However clinicians tend to divide the procedures into two main fields: lateral compaction of cold gutta-percha and vertical compaction of warm gutta-percha. All the other methods are variations of the aforementioned procedures.

Cold Lateral compaction

Lateral compaction of cold gutta-percha points (standardized gutta-percha cones) with root canal sealers is the technique that has been most commonly used by dentists. This technique includes placement of a sealer (that serves as a lining in the canal walls), followed by a primary point (previously measured). This is then compacted laterally with the use of a spreader, in order to make room for an additional point. The spreader is then used again to compact laterally and other points are used to fill the root canal space. The final mass of points is detached at the orifice of the canal with a hot instrument, and then a vertical compaction is used with a large plugger to give final compaction of the whole gutta-percha. If well executed, the result will be a solid canal obturation which will reflect the shape of the prepared root canal. However several studies have shown that this cold method has certain shortcomings, particularly in providing a fluid-proof seal of the apex.

Schilder described this technique as inefficient in that the gutta-percha cones do not melt to form a homogenous mass, but are simply "stuck in a sea of cement".[15] Backing this observation are several studies which show that the contents of gutta-percha in fillings, carried out with the lateral technique, are inferior to those achieved with other methods. Sakhale et al. have shown, however, that the cones adequately fill the canal and cover the space with only a small quantity of inter-filling cement (Figure 9).[78]

Warm Vertical compaction

At the end of the 60's, Schilder introduced the concept of obturating the space "three-dimensionally" with gutta-percha, warmed in the canal and compacted vertically with pluggers.[79] In his opinion, this is the perfect technique for sealing all the "portals of exit" that would be filled with a maximum amount of gutta-percha and a minimum amount of sealer. This technique is based on a fundamental property of gutta-percha - thermoplasticity.

The first step is the fitting of the master gutta-percha cone. A conventional cone-shaped (non standardized) point is chosen to reach slightly short of the radiographic terminus. Radiography is used to evaluate the fitting. The clinical interpretation of good cone-fitting is known as "tug-back". A small amount of cement is used. Then, using pre-fitted pluggers, and a heat carrier (heat transfer instrument), the gutta-percha is compacted, moving apically with the so-called "wave of compaction" until the pluggers reach a 5 mm distance from the radiographic terminus. Finally the back-packing step completes the root canal filling.

Over the years, many other techniques have been proposed, that are basically variations of warm gutta-percha compaction. Examples are the Thermafil core carrier system, Endotec, continuous "wave of condensation" by Buchanan (System B and Obtura; Spartan, Fenton, MO, USA), thermo-mechanical compaction by McSpadden. Among these, the most commonly used is probably the System B technique first introduced by Buchanan.[80] It is derived from the Schilder technique and is in effect a true evolution of the warm vertical compaction technique of gutta-percha. The most notable feature in the System B device is that the pluggers and heat-carriers are combined in a single instrument (one single wave of condensation until 5 mm *vs* multiple wave of condensation). Back-packing can then be done with System B cutting cones, or with Obtura (Figure 10).

Looking to the future, a number of quicker, less aggressive and more reliable methods of cleaning, shaping and obturating root canals can be anticipated. A more significant development is the use of stem cells to repair pulp tissue, currently under investigation by certain groups of researchers While extensive further laboratory and clinical research is still needed, encouraging results have already been obtained.[81]

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