Introduction to chemo-mechanical shaping of the endodontic system

The chemo-mechanical preparation phase in endodontic treatment

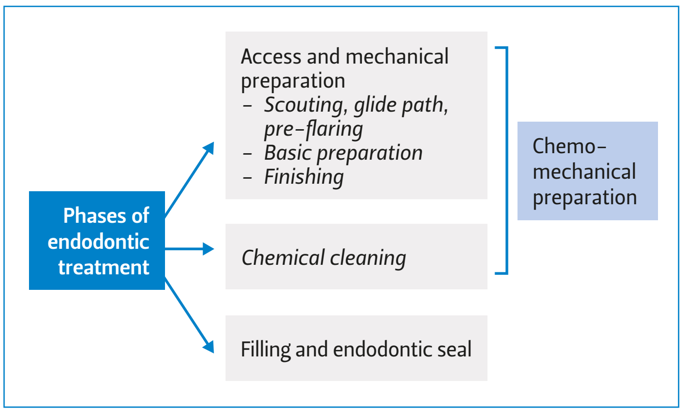
Modern endodontic treatment can be divided in three main phases as follows:

- **root canal access and preparation**: includes opening the access cavity, locating the canal orifices, scouting, "shaping" the root canal (1) and finishing the apical third;
- **cleaning**: includes root canal irrigation and use of all the techniques and technologies currently available to improve cleaning of the endodontic space and bacterial reduction;
- **obturation**: includes the three-dimensional filling of the endodontic space after shaping and cleaning have been completed.

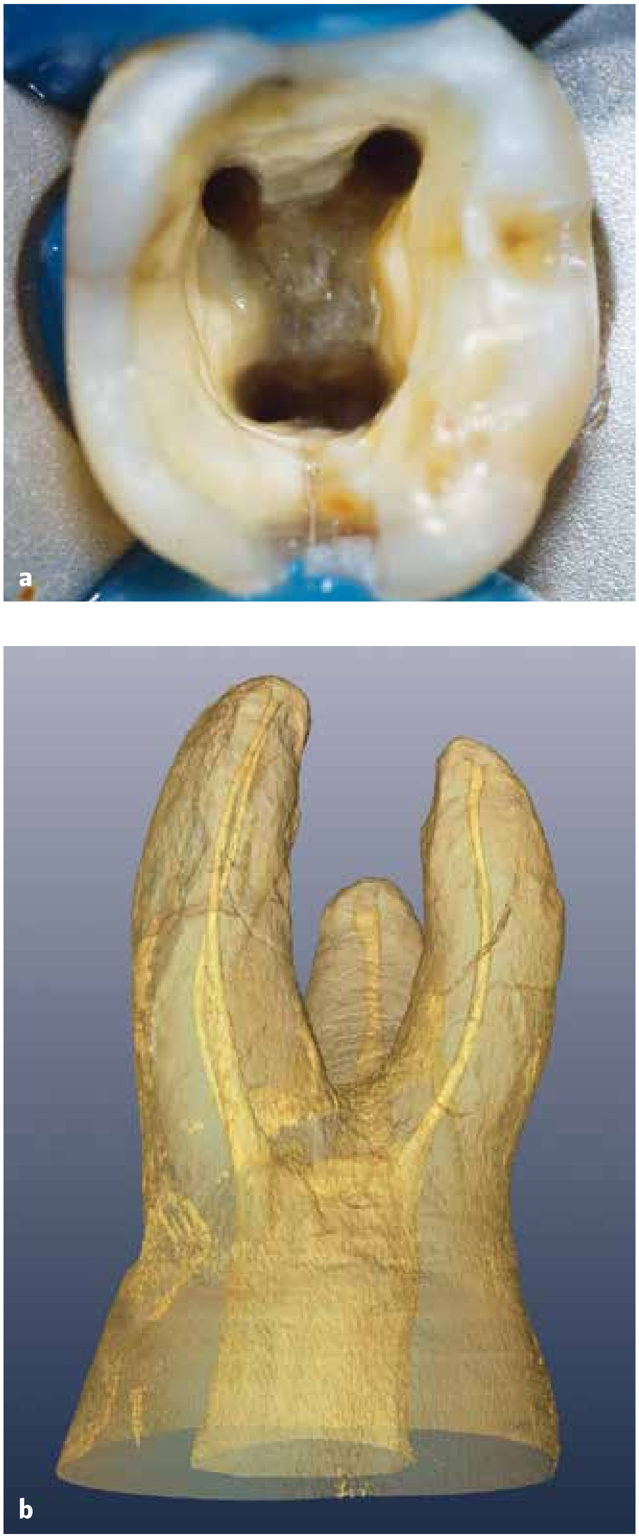
This book will focus on the first two phases, which will be described separately for organisational reasons despite being very closely interconnected in clinical practice. Indeed, the concept of chemo-mechanical preparation is based on the fact that there cannot be effective mechanical shaping of the canal without optimal chemical cleansing and vice versa (2-6).

Once a specific access cavity has been made for each clinical case to identify all the root canal orifices, the shaping phase of the root canal treatment can itself be divided into three steps (1.1):

- **preliminary step.** Made up of: the scouting phase, i.e. the initial canal assessment, in order to understand the three-dimensional endodontic anatomy of each individual canal and, if possible, to reach the apex; the glide path creation, i.e. preparing an easy and repeatable path from the orifice of the canal to the apical foramen; and the pre-flaring, i.e. the pre-enlargement



1.1 Schematic outline of the phases of the modern endodontic treatment and steps of the chemo-mechanical root canal preparation phase.



1.1 **(a)** Image of a traditionally opened access cavity with complete removal of the coronal interferences and straight-line access to root canals; **(b)** Three-dimensional reconstruction of an upper molar with a more conservative opening of the access cavity, but which still allows the instruments to access the root canals in a straight-line and without interferences.

of the glide path before using mechanical instruments (this step will be described, analysed and discussed in detail in Chapter 4 of this book);

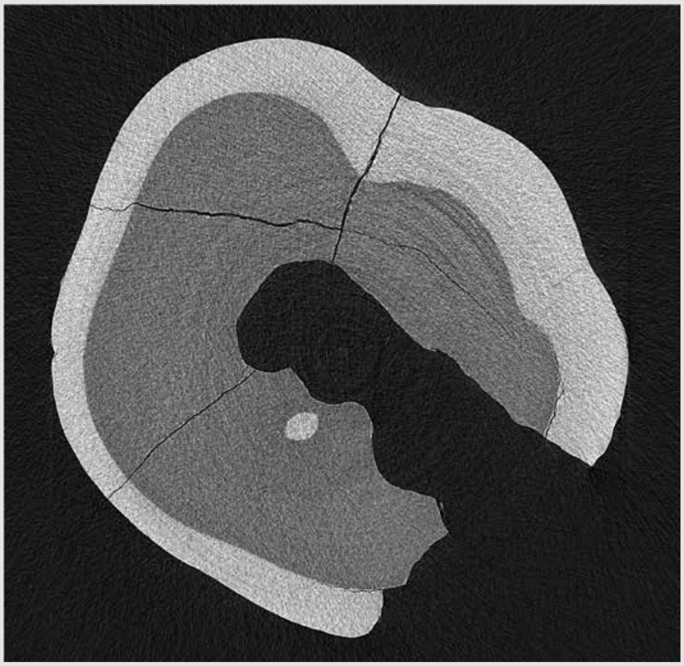
- **basic preparation step.** This includes shaping the body of the root canal along its entire length up to a basic dimension. Nowadays minimum basic preparation generally refers to instrumentation having a diameter of 0.25 mm apically and .04-.06 taper or a variable taper decreasing coronally (7) (this step will be discussed in depth in Chapter 5 of this book);
- **apical preparation step.** This calls for selective widening of the apical third with anatomically guided diameters (this step will be described in Chapter 6 of this book).

One of the main challenges faced by dentists is finding canals, particularly in those cases where the orifice has been obliterated by secondary and/or tertiary dentin, calcified by chronic pulp inflammation or procedures to maintain pulp vitality (*pulpotomy*, *capping*), or even due to the presence of restorative materials. Any preparation of the access cavity in a calcified tooth inherently involves the risk of perforating or dangerously weakening the tooth. An incorrectly performed access cavity can make the subsequent procedures more complex. Lack of a straight-line access (1.1) has often been referred to as the main cause of endodontic instruments fracture, perforations and inability to reach the apical foramen (8). Luckily, new instruments and procedures have significantly improved the predictability for a proper access cavity preparation. The use of microscope (9), specific burs and ultrasonic tips for access (8,10,11), as well as CBCT as a diagnostic tool, represent the more effective technological advancements in obtaining excellent clinical results (12). We would like to point out that, in our view, the use of high-power ultrasonic endodontic inserts (1.2) should be limited to the floor of the pulp chamber and deep dentin, because the action of ultrasound on enamel and coronal parietal dentin may result in the onset of cracks or their propagation in about 10% of specimens (1.3) (13).

In conventional procedures for opening the pulp chamber, ultrasonic tips are useful tools to adequately refine the access cavity (1.4), to locate the second canal of the mesio-buccal root in upper molars (1.5) and, in general, all hidden and calcified canals in any type of tooth (1.6, 1.7), as well as to remove pulp chamber calcifications (1.8). The increased visibility and the enhanced control provided by ultrasonic tips make them essential instruments, especially for the treatment of molars, in which access preparation can be complex for all clinicians.

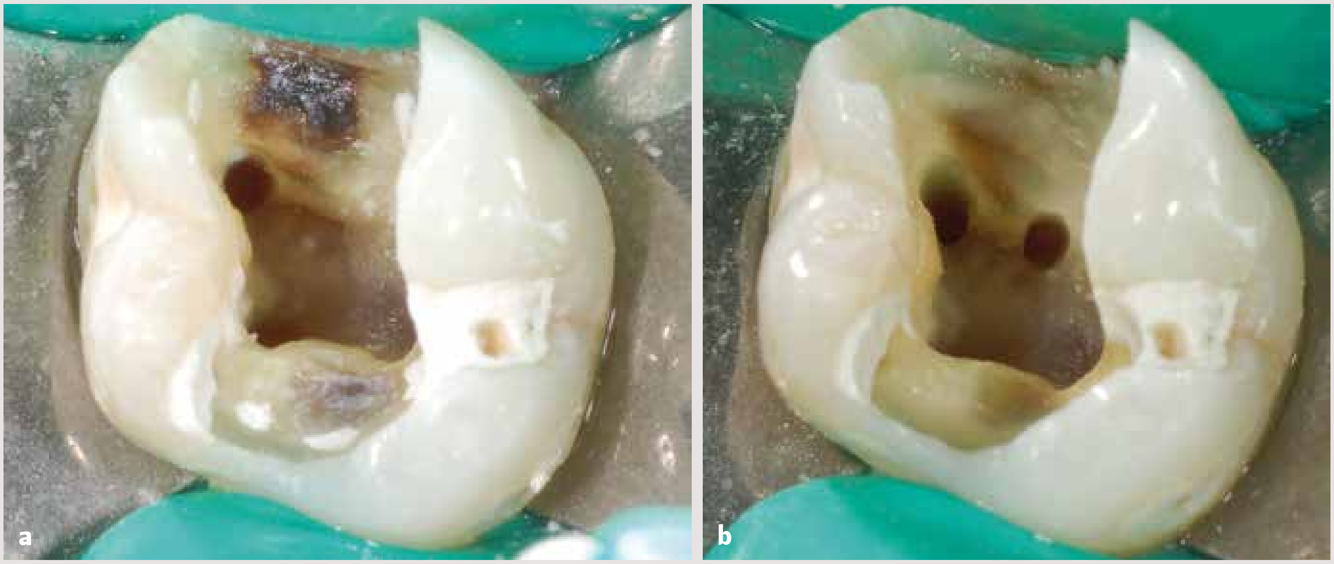
Ultrasonics are also excellent for removing the calcifications that cover canal orifices, the coronal interferences, materials and secondary or tertiary dentin. In this application, large diamond-coated tips can be used

1.2 Different types of ultrasonic inserts for finishing the endodontic access cavity. The inserts primarily differ by the attachment, available in various types depending on the manufacturer, as there is no production standard. Secondly, they differ by size, geometry and surface features. The larger and diamond-coated tips are designed for cavity finishing and have greater cutting efficiency, also linked to their suitability for use at a higher power. Conversely, the thinnest and non-diamond-coated tips can be used to explore the isthmuses and work at greater depth in the apical direction, but special attention should be paid to the power these small tips are used at, as they are usually more prone to fracture when used at high-power.

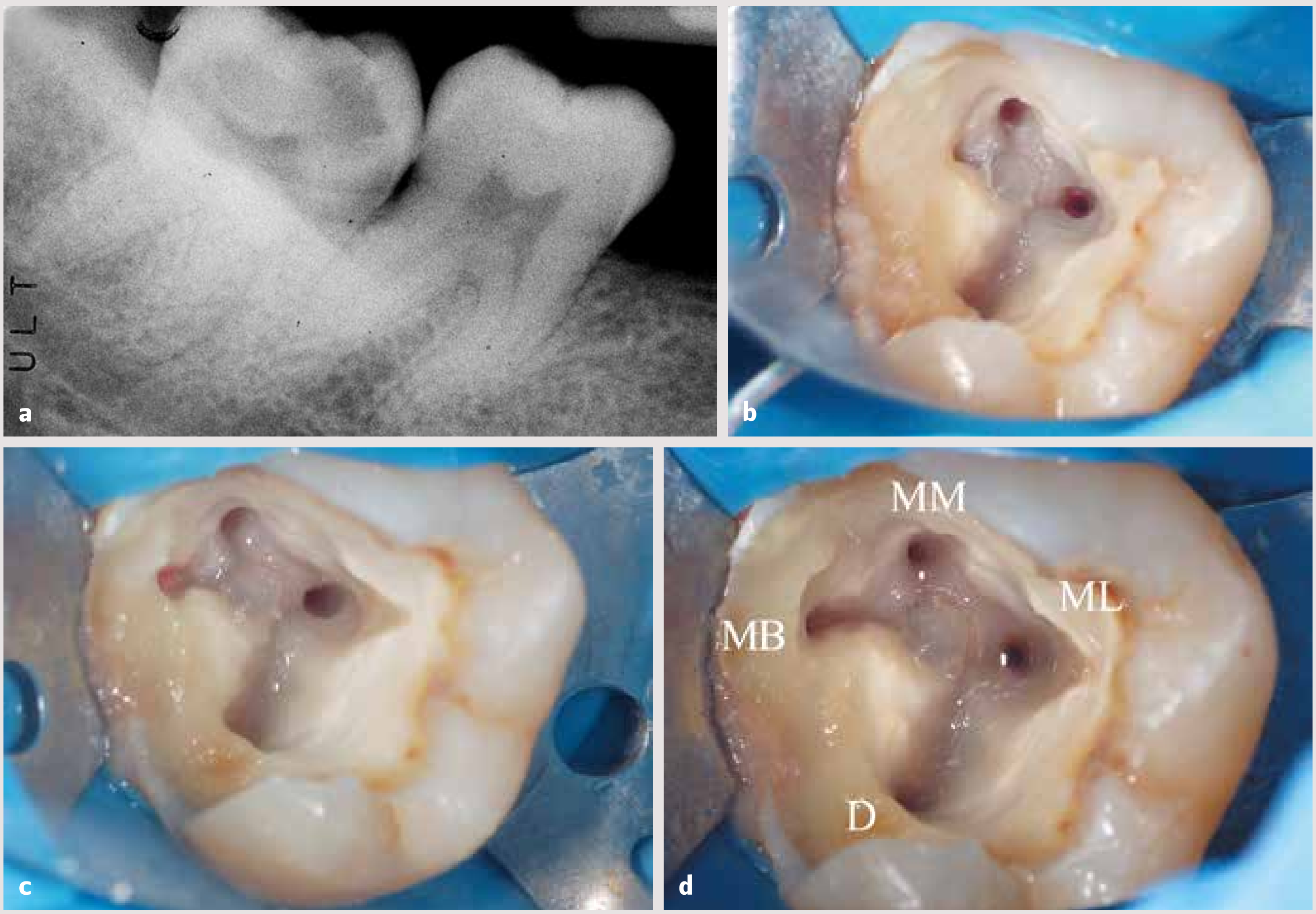


1.3 Micro-computed tomography of a specimen in which the access cavity has been refined and enlarged with high-power ultrasonic inserts, in which enamel-dentinal micro-cracks can be observed.

1.4 Clinical image after opening and finishing the access cavity.



1.5 **(a)** Calcification of the pulp chamber which completely obliterates the orifice of the second mesio-buccal canal of the first upper molar. **(b)** The orifice has been exposed removing calcifications with ultrasonic tips and then pre-enlarged with rotary nickel-titanium instruments. (From: Plotino G, Pameijer CH, Grande NM, Somma F. Ultrasonics in endodontics: a review of the literature. *J Endod* 2007; 33(2): 81–95, courtesy of Elsevier).



1.6 a–d **(a)** Pre-operative radiograph of a mandibular third molar with unusual anatomy. When opening the access cavity, four separate canal orifices are revealed, three of which located in the mesial portion of the tooth **(b)**. Clinical images during exposure of the canal orifices performed with ultrasonic tips **(c,d)**. (Figures a, d from: Plotino G. A Mandibular Third Molar with Three Mesial Roots: A Case Report. *J Endod* 2008;34:(2)224–226, permission granted by courtesy).

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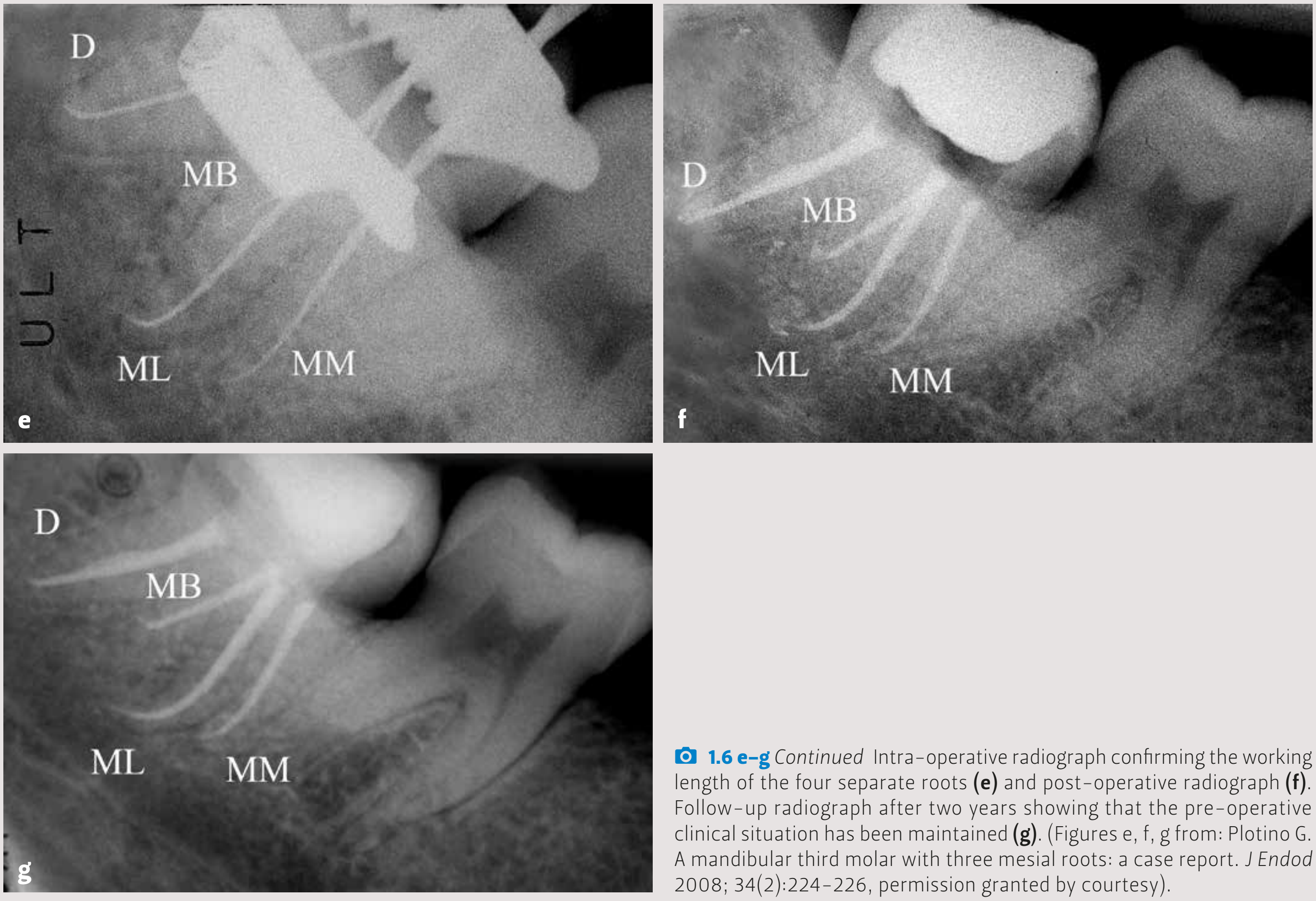
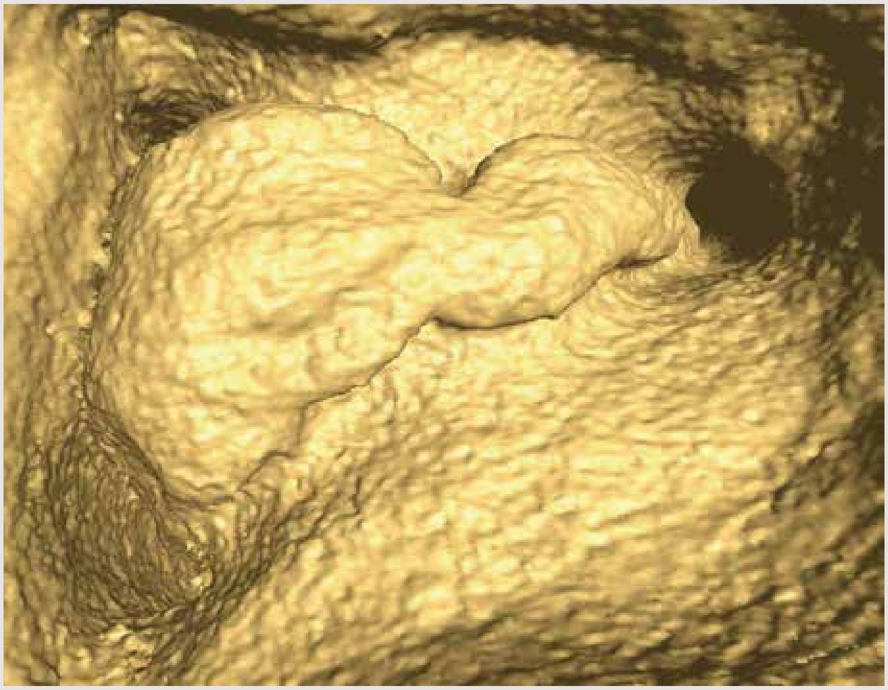
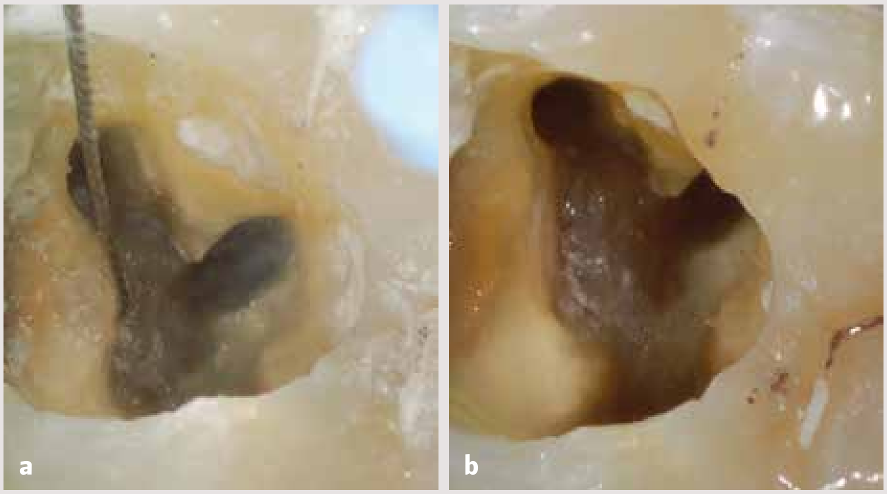


1.6 e–g *Continued* Intra-operative radiograph confirming the working length of the four separate roots **(e)** and post-operative radiograph **(f)**. Follow-up radiograph after two years showing that the pre-operative clinical situation has been maintained **(g)**. (Figures e, f, g from: Plotino G. A mandibular third molar with three mesial roots: a case report. *J Endod* 2008; 34(2):224–226, permission granted by courtesy).

1.7 Upper premolar with a calcified palatal canal orifice **(a)** in which the chamber calcifications were removed with ultrasonic endodontic tips **(b)**.



1.8 Three-dimensional reconstruction of a micro-computed tomography scan showing extensive calcification of the pulp chamber floor of a lower molar, partially obliterating the root canal orifices.



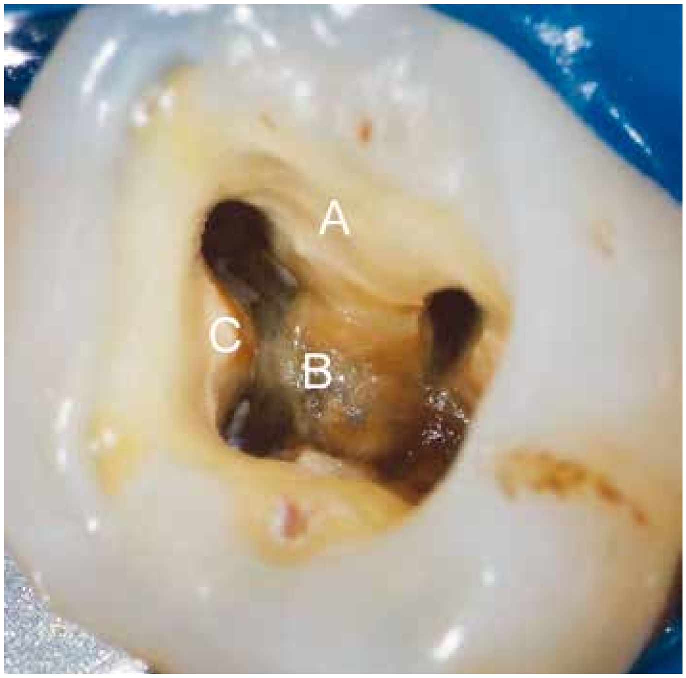
1.9 **(a)** Clinical image showing the orifice of the MB2 canal of an upper molar covered by a significant amount of dentin which obstructs its access. **(b)** Clinical image of the exposure of the orifice after dentin removal with an ultrasonic tip.

in the early stages, while thinner and longer non-diamond-coated ones can be used subsequently in the deepest areas. In finding the MB2 canal of the upper molars, ultrasonics are excellent in removing the dentin that is often attached to the mesial wall and obstructs the access to its orifice (1.9). Ultrasonic tips with a pointed end are not suitable for this purpose as they may damage the grooves in the pulp chamber floor, which are often important guides in finding the root canal orifices (1.10). A good reference to keep in mind when searching for hidden canals is that secondary dentin is generally whitish or opaque, whereas the chamber floor is darker and greyish (1.11) (14).

Objectives of root canal shaping

Most pulp and peri-radicular diseases dealt with in daily clinical practice are caused by the presence of micro-organisms. All the literature since the 1960s and 1970s agrees in pointing to and underlining this issue (15–20). This is why the main goal of the therapy must be to perform disinfection of the endodontic space as accurately

1.10 Floor of the pulp chamber of an upper molar with particular anatomy (four canals in four separate roots) clearly showing the darker grooves which run along the surface of the floor and can be very useful in finding the canal orifices.

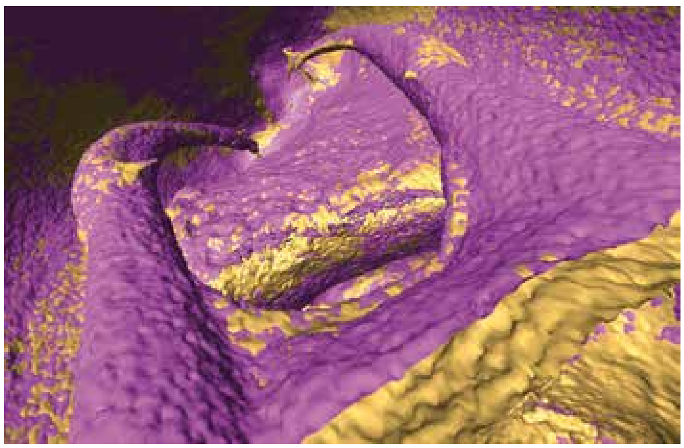


1.11 Floor of the pulp chamber of a first upper molar after finding and widening the orifices. Different dentin shades can be observed: parietal dentin appears clear and uniform **(A)**, the dentin of the pulp chamber floor appears to be darker, greyish and more translucent **(B)**; the pathologically damaged dentin appears to be dark brown and opaque (tertiary dentin) **(C)**. A large amount of dentin covering the orifice of the MB2 canal should be eliminated for its correct instrumentation.

as possible, and to prevent its re-infection (19,21,22). Obviously, while reducing the number of microorganisms and debris present in the endodontic system to a minimum is the main goal of endodontics in general, this must also be the main objective of the instrumentation phase (23).

Nowadays, according to scientific evidence, it is a well-known fact that mechanical instrumentation alone can significantly reduce the number of remaining microorganisms in the root canal, even without using irrigating agents and medications (4,6). It is also widely known that mechanical instrumentation alone, while significantly reducing the percentage of bacteria present, is unable to thoroughly disinfect an infected root canal system (5). It has been clearly demonstrated that none of the currently available instrumentation techniques has the ability to clean and shape the entire endodontic space. In fact, the percentage of walls touched by mechanical instrumentation is significantly lower than the ideal goal (24,25) (1.12).

While mechanical preparation alone cannot guarantee the reduction of the intra-canal bacterial load unless effective chemical irrigation is performed, it is also true that irrigants without adequate mechanical preparation also have no ability to reduce endodontic infection below a threshold which ensures good decontamination

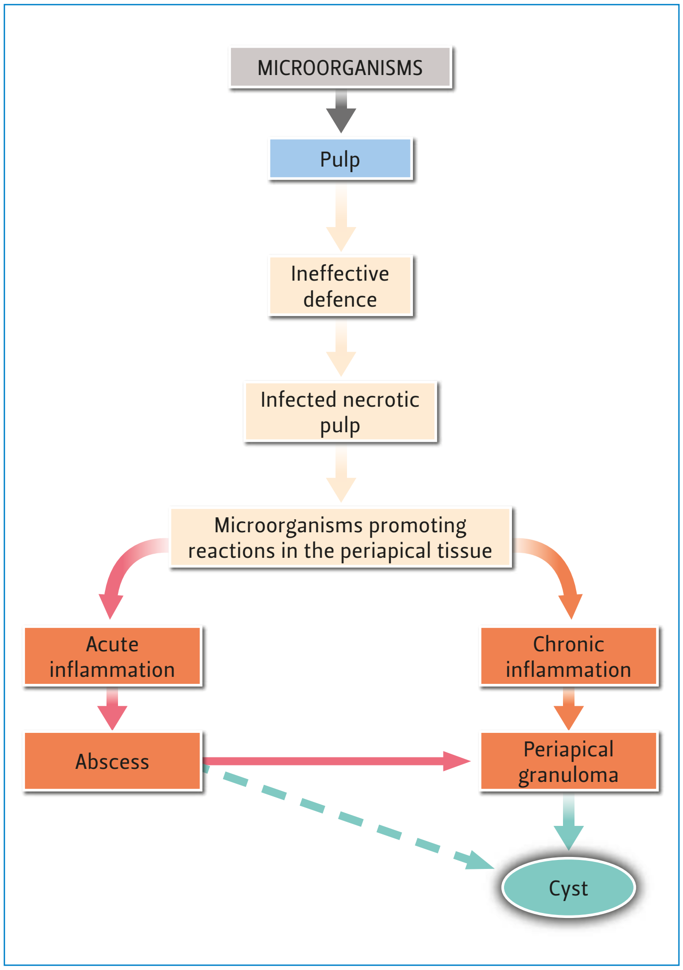


1.12 Three-dimensional reconstruction of the superimposition of the micro-computed tomography scans of two mesial canals in a lower molar before (in yellow) and after (in purple) the instrumentation. The areas in yellow still exposed in the superimposition with the post-instrumentation scan represent the areas not touched by the mechanical instruments and demonstrate that touching 100% of the canal walls with the instruments is impossible.

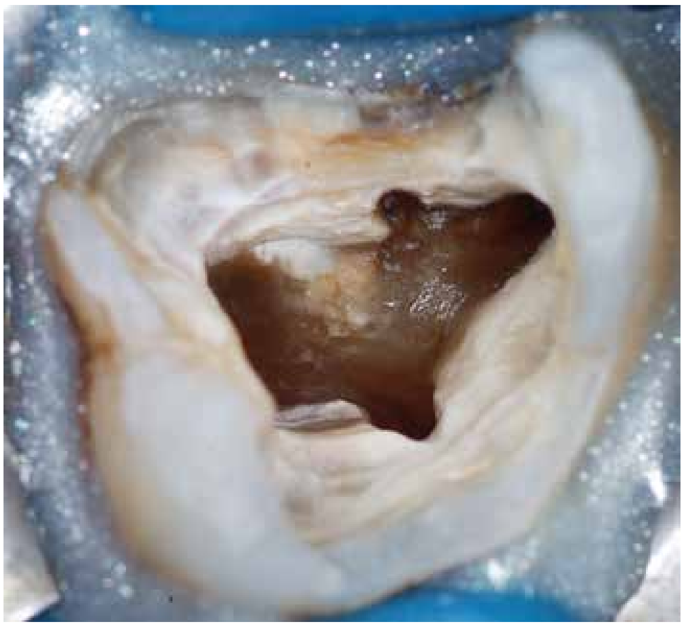
and cleaning (2,3,5). The available evidence, therefore, shows that we are unable to completely sterilise the endodontic system through either mechanical or chemical disinfection and that we should use both synergistically to achieve the maximum possible result in what we shall refer to as the chemo-mechanical preparation phase (26).

Although complete eradication of the infection from the entire root canal system is the ideal goal, realistically the best result achievable through endodontic therapy is a maximum reduction of the microbial population within the canals of an infected tooth to bring the bacterial count to levels that are compatible with healing of the peri-radicular tissues (20) (1.2). In the case of vital and uninfected teeth, the state of asepsis present before treatment should not be altered, therefore the main goal of endodontic therapy is to prevent the entry of new microorganisms where there are none originally. In this case, the main purpose of the instrumentation phase is simply to empty the intra-canal contents from non-infected organic tissue and enlarge the endodontic space in order to remove the tissue both mechanically, through the action of the instruments, and by promoting the chemical action of irrigants, which need space to be effective. It has been repeatedly observed in literature that irrigants require at least a minimum canal enlargement to achieve complete dissolution of the organic component of the pulp within the endodontic anatomy (27,28). In cases of "vital pulp", we will therefore need to implement all possible strategies and measures to avoid bacterial contamination during treatment (29) and ensure proper isolation of the operating field, in order to tightly separate it from the oral cavity, which is a highly contaminated space (30,31) (1.13).

The complete emptying of the endodontic space is also required to prevent any post-treatment residual bacteria from finding fertile ground for its new growth and compromising long-term clinical success. At the same time, a tight endodontic and restorative coronal seal must be promoted to prevent any re-infection of the endodontic system. The role played in the maintenance of endodontic infection by other possible pathways for bacterial penetration, such as the dentinal tubules (32–34), any leakage areas of the post-endodontic restoration (35) or other possible hypotheses, such as "anachoretic" infection (36) or transient septicaemia



1.2 Diagram of the microbial endodontic disease onset, in which microorganisms appear to be the primary pathogenetic agents able to invade the pulp organ and subsequently cause reactions in the periapical tissue. Endodontic treatment may stop the onset of the disease.



1.13 Complete isolation of the operative field, necessary to prevent endodontic contamination during treatment.

of systemic origin, is still controversial. However, it is clear that the presence of areas with organic content, albeit not infected, may pose a high risk for the success of the treatment in the long term (37,38). As we will see in the specific chapter on this topic, the root canal irrigation sequences will be quite similar regardless of the state of sepsis of the endodontic space, although the ideal aim of these procedures is different. Indeed, in the case of a non-vital and infected tooth, the main purpose will be to fight against the presence of bacteria and microorganisms within the anatomy, while the primary purpose in aseptic teeth is to prevent infection of the endodontic system.

The fact that the success rate reported in the literature for vital teeth is found at best to be around 90-95% (39) is somewhat discouraging, as theoretically this should be closer to 100% since before therapy there are no microorganisms in the endodontic space. One may assume that the failures in aseptic cases are linked to iatrogenic errors such as the inadequate maintenance of the sterility of the operating field or of the instruments used (29).

In light of these remarks, we have defined the shaping of the root canal as a phase for endodontic infection control through instrumentation, where infection control refers to prevention and treatment of this pathogenic component.

In this book, we will deal in detail with the various steps of root canal preparation and shaping (£ 1.1), but, before we can describe the clinical operating steps, we need to provide an overview of the type of instruments available today, the materials and technologies to manufacture them and the techniques and movements they can be used with.

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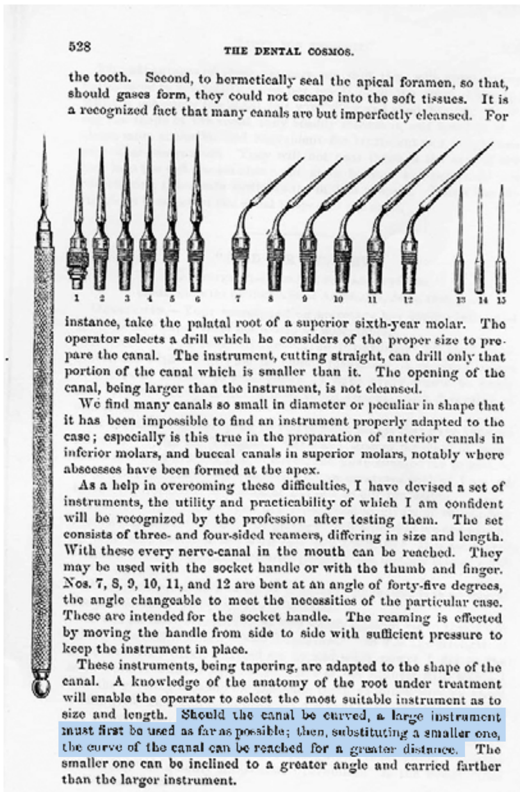
Basic principles of chemo-mechanical shaping of the endodontic system

Evolution of the principles of chemo-mechanical shaping

For a proper approach to modern endodontic instrumentation, we must refer to the preparation techniques that were described and used in the past and of which the modern variations are only technologically advanced derivations. The roots of current endodontics lie in the last decades of the nineteenth century, when a number of authors noted the importance of shaping the canal using manually operated files, in order to eradicate bacterial infection (1-6). To our knowledge, the first description of an instrumentation technique with corono-apical approach (**crown-down**) was introduced by Talbot, who in the historical journal *Dental Cosmos* in 1880 (7) (2.1) wrote: "*Should the canal be curved, a large instrument must first be used as far as possible; then substituting a smaller one, the curve of the canal can be reached for a greater distance*" (7). The essential principle of the pure crown-down approach is clear in Talbot's description, namely, to pave the way with larger and more rigid instruments used in the more coronal portions of the canal, which are easier to reach and pose lower iatrogenic risks, in order to subsequently be able to reach the most apical portions of the root ca-


528 THE DENTAL COSMOS.

the tooth. Second, to hermetically seal the apical foramen, so that, should gases form, they could not escape into the soft tissues. It is a recognized fact that many canals are but imperfectly cleansed. For

instance, take the palatal root of a superior sixth-year molar. The operator selects a drill which he considers of the proper size to prepare the canal. The instrument, cutting straight, can drill only that portion of the canal which is smaller than it. The opening of the canal, being larger than the instrument, is not cleansed.

We find many canals so small in diameter or peculiar in shape that it has been impossible to find an instrument properly adapted to the case; especially is this true in the preparation of anterior canals in inferior molars, and buccal canals in superior molars, notably where abscesses have been formed at the apex.

As a help in overcoming these difficulties, I have devised a set of instruments, the utility and practicability of which I am confident will be recognized by the profession after testing them. The set consists of three- and four-sided reamers, differing in size and length. With these every nerve-canal in the mouth can be reached. They may be used with the socket handle or with the thumb and finger. Nos. 7, 8, 9, 10, 11, and 12 are bent at an angle of forty-five degrees, the angle changeable to meet the necessities of the particular case. These are intended for the socket handle. The reaming is effected by moving the handle from side to side with sufficient pressure to keep the instrument in place.

These instruments, being tapering, are adapted to the shape of the canal. A knowledge of the anatomy of the root under treatment will enable the operator to select the most suitable instrument as to size and length. Should the canal be curved, a large instrument must first be used as far as possible; then, substituting a smaller one, the curve of the canal can be reached for a greater distance. The smaller one can be inclined to a greater angle and carried farther than the larger instrument.

2.1 The first description of a crown-down technique carried out by Talbot in 1880 (*Preparation of nerve canals for treatment and filling*. Dental Cosmos 1880; 22:527-29).

nal with smaller and more efficient instruments, more safely and effectively.

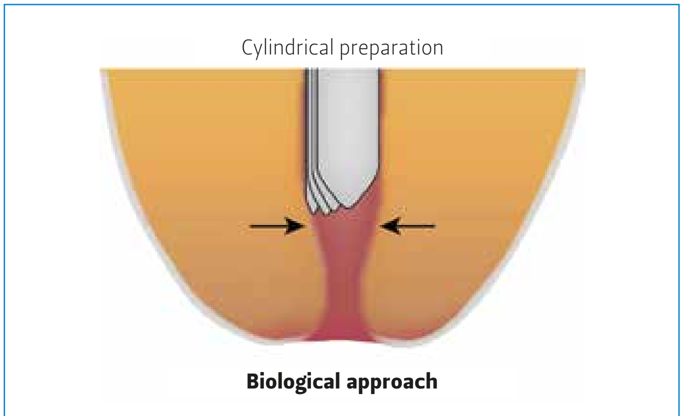
The spread of the concept of focal disease in the early decades of the twentieth century significantly slowed down the development of the endodontic specialty, and it was not until the second half of the century that some "endodontists", seen as brave pioneers, would put forth again the basis for scientifically predictable endodontics (8-10).

The american endodontist Louis Grossman may be considered one of the key players of this rebirth, laying the foundations for the endodontic specialty with other colleagues (11-14). At that time, instrumentation of the root canals was performed with steel instruments, first made in carbon-steel then in stainless-steel (15,16). The features of the various types of steel instruments and their manufacturing processes will be described in Chapter 3.

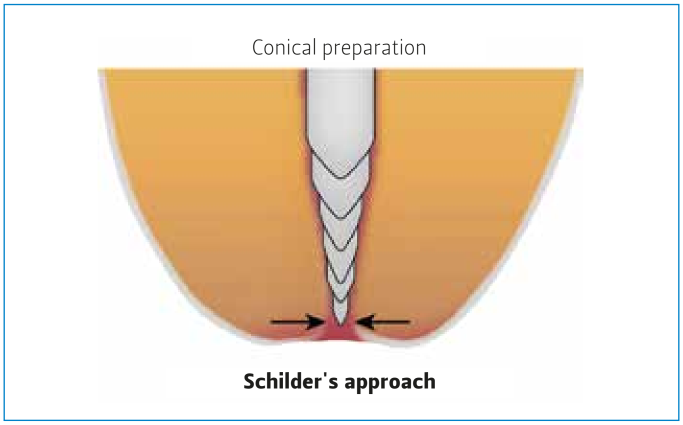
At that time, in the early years of the post-second world war period and after the introduction of instrument standardisation promoted by Ingle (17) in the 1960s (described in Chapter 3), the approach to root canal instrumentation required a strict respect of the anatomical structures at the level of the cemento-dentinal junction. We might define it as "**biological**" instrumentation. From a geometrical point of view, it reflected the shape of the steel instruments on the market at the time. The canal was therefore shaped with a minor degree of taper (.02) tending to be very close to a cylindrical shape, but with large diameters at the apical limit of preparation, a limit that today might be seen as rather "short" compared to the current concept (2.2).

The onset of the principles put forth by Herbert Schilder in the late 1960s changed forever the concepts underlying the instrumentation of root canals (18). Schilder emphasised the importance of maintaining the endodontic morphology during instrumentation, with a special focus on the delicate and complex apical areas. The final goal was to seal the root canal system with warm gutta-percha condensation techniques (19). These concepts led to a more "**mechanicistic**" approach to endodontics, in which greater importance was given to the mechanical action of the instruments and the hermetic obturation of the endodontic space, rather than the application of antibacterial dressings and the biological action of medications and materials used during treatment. The type of preparation popularised by Schilder involved a canal preparation with increasing diameters starting from the apical foramen towards the crown, with a continuous tapered shape. A special focus was given to maintaining the original apical diameters and reaching the working length up to the radiographic apex (2.3). The mechanical preparation and cleaning stages were considered more important than absolute respect for tissues at apical level. Furthermore, Schilder was the first to emphasise the principle by which the mechanical preparation, especially if tapered, should promote the cleaning action of irrigants in the apical area and in those inaccessible areas that cannot be reached by the action of the instruments (20).

Schilder's technique still entailed the use of steel hand instruments. These type of instruments in medium and large diameters (i.e., from 20 upwards) feature high rigidity so, in an effort to prevent the likelihood



2.2 Schematic outline of the apical preparation without taper and with a "step" according to the "biological school" with different principles and purposes from the Schilder preparation.



2.3 Schematic outline of the apical preparation with constant taper up to the apical foramen and keeping the latter as small as possible, as described by Schilder's principles.

of altering the apical anatomy, Schilder himself introduced the **step-back technique**. This method entailed the use of instruments with increasing diameters in apico-coronal direction, in order to achieve the desired conical shape. The technique also entailed maintaining apical **patency**, with frequent recapitulations, moving the thinnest instruments up to the radiographic apex, in order to maintain patency of the entire canal and apical foramen.

The apico-coronal approach introduced by Schilder still remains a valid technique for the preparation of the root canal using manual files.

In the 1980s, hybrid techniques were put forth, building on Schilder's concepts. After an initial stage of canal negotiation, enlargement in the corono-apical direction (**crown-down**) in the coronal and middle thirds (to achieve rapid elimination of potential coronal interferences) were followed by **step-back** phases, limited to the last apical millimetres of the root canal.

One of these techniques was initially published by Goerig et al. (21) and then popularised in the 1990s by Scianamblo and Ruddle; it may be included among the **step-down** techniques (22–24). It first required a mainly passive action of steel instruments, both rotary and manual; after negotiating the canal as far as possible, the canal body was widened by using a sequence of hand instruments, operated passively as far as they could get without forcing them, in order to open the way for mechanical instrumentation, performed with Gates Glidden drills. In this technique, it was essential for instruments and drills to work outwards, removing interference of the middle and coronal third, in order to be able to proceed towards the deeper areas of the canal without hindrance. The apical third was then negotiated and widened only with hand instruments in **step-back** mode, as taught by Schilder (2.1).

As we have mentioned, the corono-apical approach had already been implemented more than a century earlier (7), however we owe Dr. Riitano for the first proposed entirely mechanical technique with a **crown-down** approach (25–28). The **"Three Step"** technique entailed the use of increased taper instruments: the Rispi (2.4). These steel instruments were operated by a handpiece with an *alternating motion* (29,30) and followed the concept of removing coronal interference to promote the penetration of the subsequent instrument to a greater depth. The apical area was therefore prepared following circular enlargement concepts that were very close to the principles we currently follow during this stage, and which will be described in detail in Chapter 6.

The introduction of nickel-titanium (NiTi) instruments in the late 1980s radically changed the scenario and possibilities in this field, so much that it can be considered a real revolution in endodontic instrumentation (31). This alloy was initially proposed by three authors, who almost simultaneously understood its incredible potential in the field of endodontics. Following the scientific work by Walia et al. (32), Steve Senia, John McSpadden and Ben Johnson, well-known US endodontists, conceived the idea of an endodontic instrument built in NiTi alloy. This led to different and peculiar interpretations: the first instruments launched on the endodontic market were the McXim, designed by McSpadden, which subsequently evolved into the Quantec (2.5). The LightSpeed (2.6) instruments, designed by Senia, differed completely from the others that have been seen later, since they were shaped according to the principle of Gates Glidden drills. Finally, ProFiles (2.7) appeared, designed by Ben Johnson, still in use today and embodying one of the historical designs for NiTi rotary instruments, the so-called **U-shape**. The introduction of these instruments resulted in a drastic change in the concept of canal preparation, made possible by the mechanical features of the NiTi alloy in the appropriate dimensions for manufacturing an endodontic instrument. Its properties, investigated in a large number of studies in the literature (33,34), make it possible to "sculpt" the preparation within the canal with a geometry that is similar to that of the instrument, which therefore tends to "shape" the canal according to its design, thanks to the introduction of instruments with increased taper.

This approach was not possible with stainless-steel instruments, which are too rigid for their shape and dimensions to be compatible with the ideal tapered shape of the canal. Before the introduction of NiTi in fact, the instruments were used to "carve" the preparation in the canal, alternating their size and depth of use, with the purpose of shaping the canal with the ideal preparation. This overturning of the concept of canal shaping is the main reason for the great success and extremely rapid spread of these type of instruments, thanks above all to their main strengths: their simplicity of use and user-friendliness in achieving the purpose for which they were designed.

The many advantages in the use of NiTi instruments, in particular, are the possibility of achieving a more "centred" preparation within the root canal, consequently maintaining the original anatomy (34,35); the reduction in the number of instruments to be used and the greater simplicity of the operating procedures, with a consequent reduction in working times; and

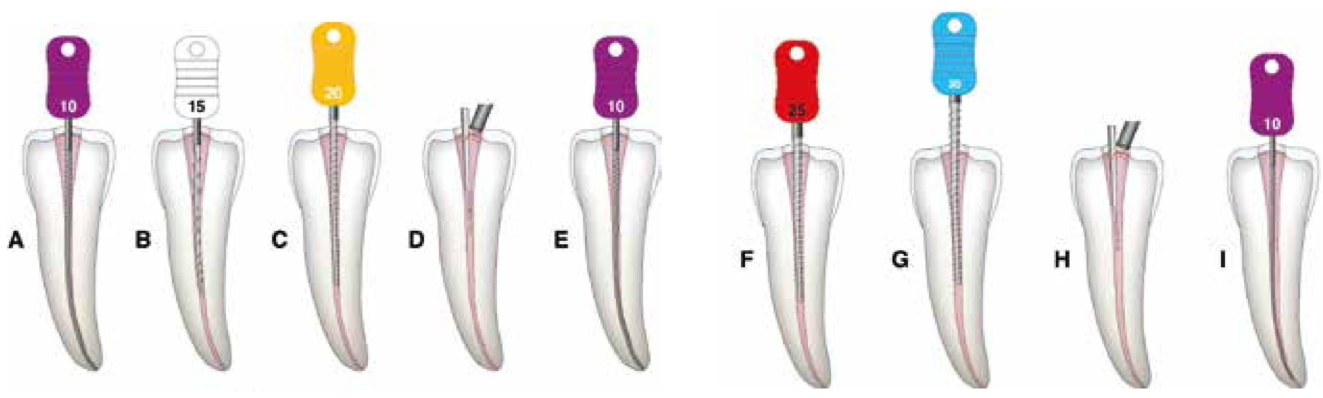
MODIFIED STEP-DOWN TECHNIQUE (SCIANAMBLO & RUDDLE)

STEPS

1. Pre-flaring
2. Early coronal enlargement
3. Apical scouting
4. Middle third preparation
5. Preparation of the middle-apical area
6. Connection
7. Apical finishing

When using manual techniques with steel instruments, the principles of straight-line access and early removal of interference should be very thoroughly adhered to. Manual steel instruments are "safe" in terms of mechanical resistance, because they are not used in continuous rotation, but with less effective and more controllable movements, as well as because of their plasticity, which causes deformation to be usually visible before fracture. However, their high rigidity may result in iatrogenic damage such as ledges, apical perforation and loss of canal patency much more easily than with NiTi instruments. The greater accumulation of debris means a copious irrigation system is essential, along with frequent "recapitulations" with smaller instruments to ensure apical patency at every stage of preparation.

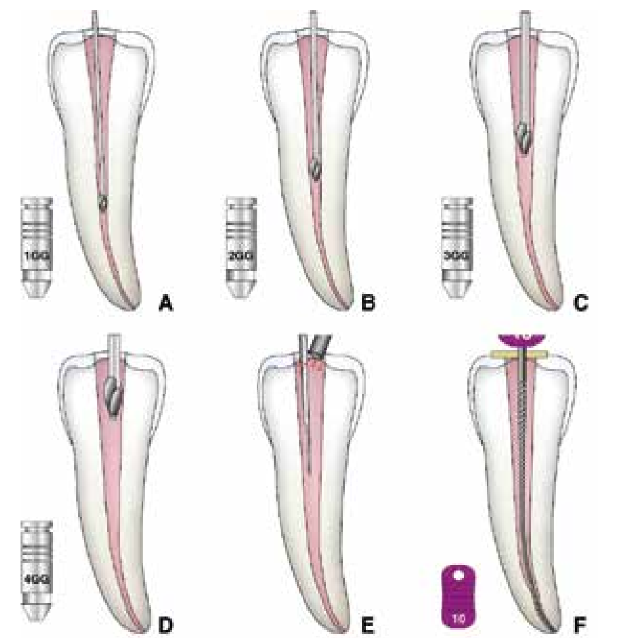
1. PRE-FLARING



After opening the conventional access cavity and finding the canal orifices, a first pre-flaring stage is carried out, without worrying about probing the canal up to the apical third. Manual steel instruments of increasing size are operated passively in apical direction until encountering mild resistance to advancement **(A,B,C)**. They are then used actively on the walls in coronal direction with filing motions (back and forth). At this stage, size 10 up to 30, 35 or 40 K-files are used (or similar instruments), according to the initial canal dimension **(F,G)**. After using each file of increasing size, copious irrigation is performed with sodium hypochlorite **(D,H)** and one returns to the initial engagement point passively with the initial instrument (usually a size 10 K-file) **(E,I)**. As an alternative, Hedström files may also be used at this stage and, in the case of very calcified canals, the use of EDTA as an irrigant or in gel form may be recommended.

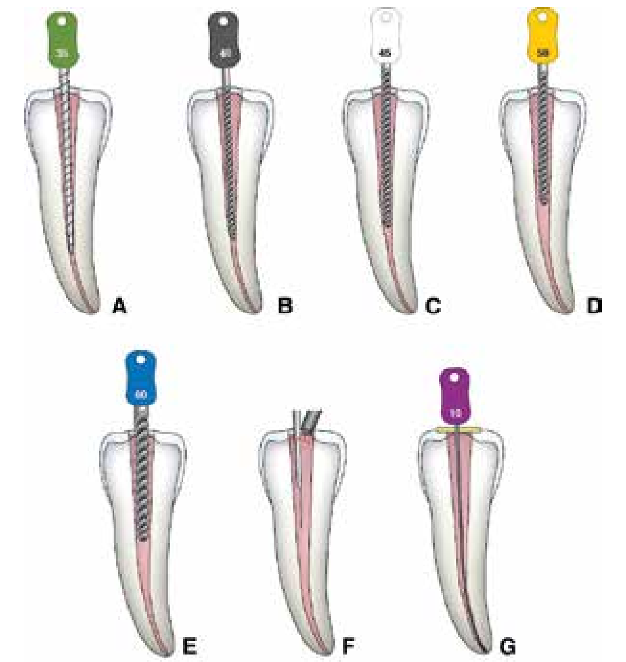
2.1 Scianamblo and Ruddle technique for the preparation of root canals, one of the most advanced techniques for shaping and cleaning root canals before the introduction of NiTi instruments.

2. EARLY CORONAL ENLARGEMENT



Gates-Glidden drills are used passively from the smallest to the largest, in apico-coronal direction **(A–D)**. This step-back action of coronal enlargement is carried out jointly with copious irrigation **(E)** and frequent recapitulations with small steel files **(F)**.

4. MIDDLE THIRD PREPARATION

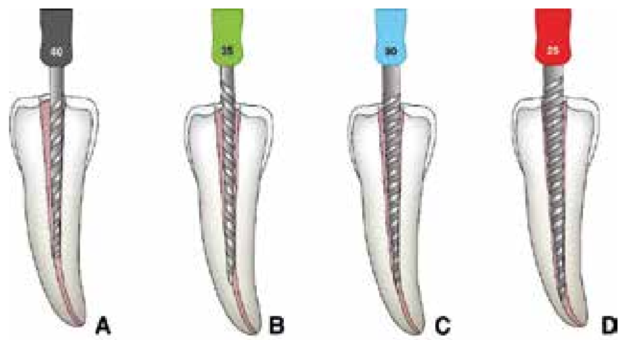


After determining the working length, larger K-files are used, once again with a step-back action and passive cut, outwards, aimed at enlarging the middle third area of the canal **(A–E)**. This stage is also carried out jointly with generous irrigation **(F)** and repeated recapitulations **(G)**.

3. APICAL SCOUTING

The working length and apical patency are determined with small steel K-files (.08, .10) operated with gentle, watch winding motion.

5. MIDDLE-APICAL THIRD PREPARATION

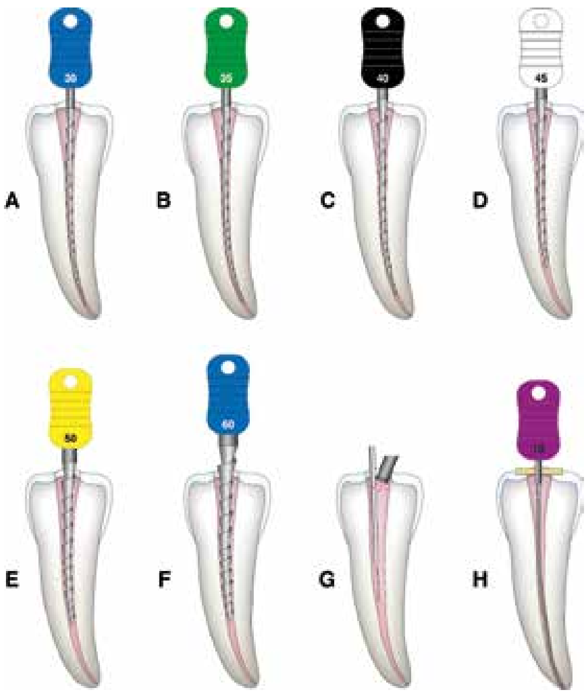


A crown down enlargement is carried out, with active cutting of the area right next to the working length, using smaller K-files than those used previously (<.35). At this stage, the aim is not to obtain the final tapered shape, but to prepare for the final step through this enlargement, which aims at deep shaping the area right next to the working length.

2.1 *Continued*

Continues

6. CONNECTION



By using medium-large Hedström instruments (from 30 to 60 and above), the two preparations previously performed are connected, trying to make the canal shape as flowing and regular as possible, in order to finalise the preparation and shaping of the most delicate area – the apical third – in the next step. Also at this stage, copious irrigation and recapitulations are essential to maintain patency and ensure effective cleaning.

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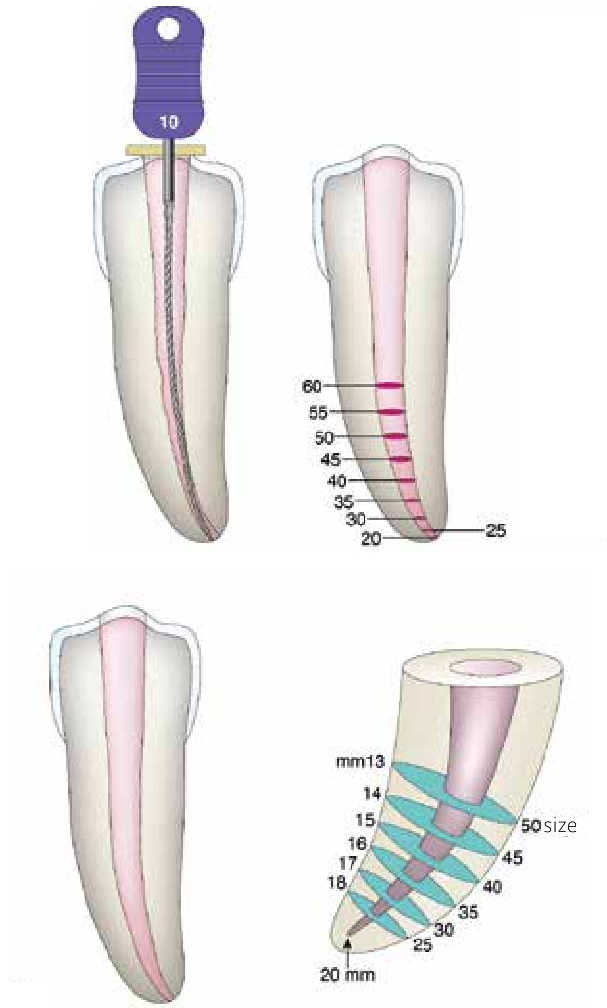
7. APICAL FINISHING



In the last and most delicate step of the shaping process, the final diameter is obtained at the end of the prepared canal (radiographic working length) and, starting from that, a preparation with increasing diameters in coronal direction is performed (step-back). The previous procedures for enlargement of the coronal and middle third ensure freedom and safety of action for the steel K-files used at this stage in a "semi-active" manner. We emphasise once again how copious and careful irrigation, jointly with recapitulations, are essential for the success of the technique.

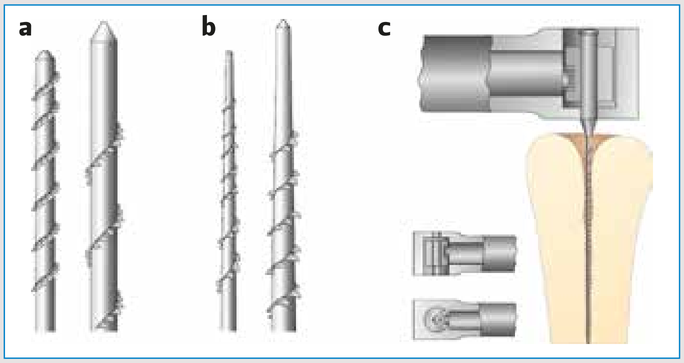
2.1 *Continued*

ultimately, the possibility of simplifying treatments previously considered for experts only. All these advantages led to the adoption of NiTi files as an integral part of the daily endodontic clinical practice.

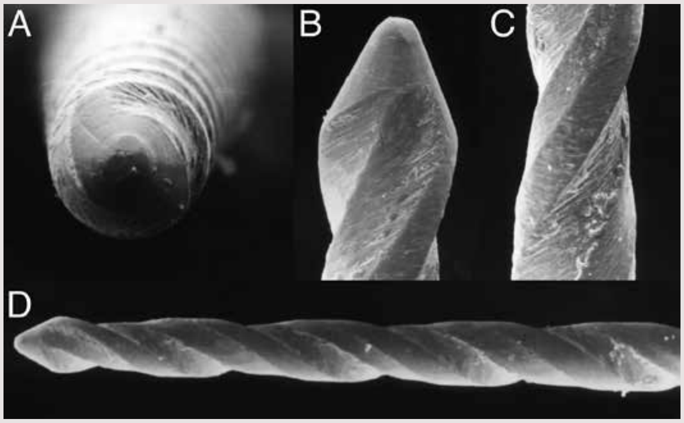
During their albeit short history, NiTi instruments have undergone a continuous evolution, probably also due to the market logistics related to their production. Essentially, the main changes since their introduction until the end of the first decade of the 2000s, were the evolution of instrument shape and design, which resulted in an increased cutting efficiency and flexibility (2.8). These two notable features subsequently led to a change in the proposed operative sequences for their use (36).

The cross-sections with greater cutting ability, less metal mass and therefore greater flexibility have made it possible to develop increasingly simple operative sequences, with a further reduction in the number of instruments required to complete canal preparation and a simpler and more predictable approach to shaping (37).

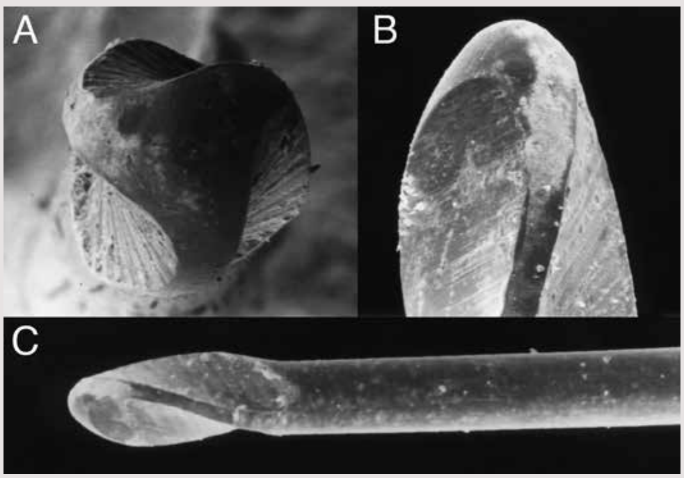
In the "classic" crown-down approach, which had characterised the debut of NiTi instruments, larger instruments are used in the coronal areas to open the way to smaller instruments in the more apical areas. Such approach has undergone clear evolutions. Drawing a parallel with the aforementioned pioneering article by Talbot (7), we can say that this approach was



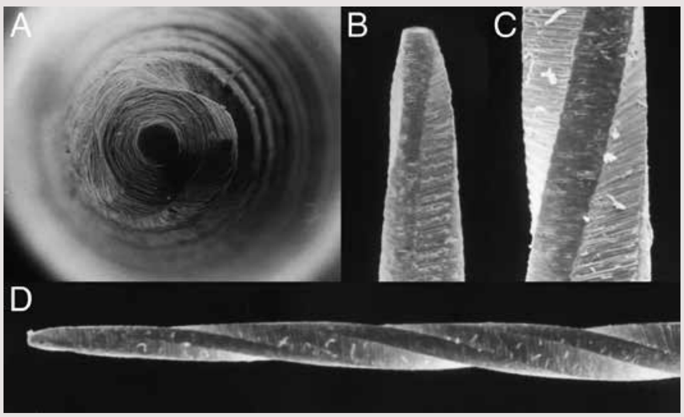
2.4 The Rispi instruments, designed by Dr Riitano and by Dr Spina **(b)** similar to the "Laurichesse shapers" **(a)**, but with increasing taper and fixed diameter tips, may be considered the first instruments to perform crown-down mechanical preparation.



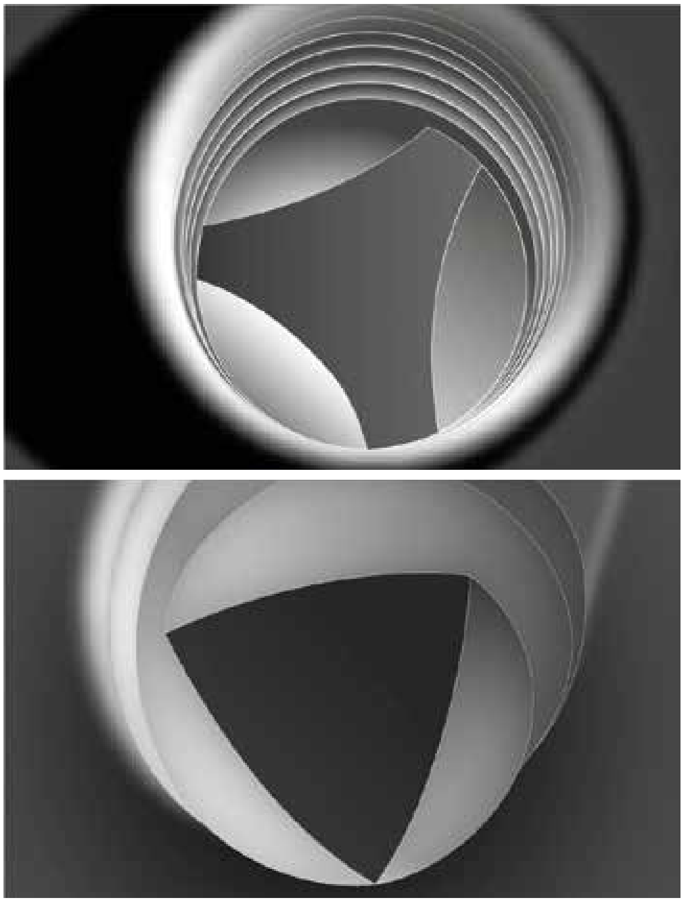
2.5 Axial **(A)** and side **(D)** views and details of the tip **(B)** and blade **(C)** of the Quantec SC instrument, observations made with SEM (Scanning Electron Microscope) between 600X and 500X.



2.6 Axial **(A)** and side **(C)** views and details of the tip and blade **(B)** of the LightSpeed instrument, observations made with SEM (Scanning Electron Microscope) between 60X and 500X.



2.7 Axial **(A)** and side **(D)** views and details of the tip **(B)** and blade **(C)** of the ProFile instrument, observations made with SEM (Scanning Electron Microscope) between 60X and 500X.



2.8 Two types of triangular section for NiTi rotary instruments. At the top a triangular section with cutting planes, at the bottom a triangular section with cutting blades. The changes in the instrument sections have contributed to the evolution towards increasingly efficient designs in cutting dentin and led to a simplification in instrumentation sequences.

essential for using instruments that were more flexible than stainless-steel, but still a bit rigid and, above all, with low cutting efficiency, limits similar to those that Talbot experienced one hundred years earlier. In both cases, the technique demanded dividing the cutting areas into sectors, thus reducing the impact area of the blades on the dentinal surface. With the introduction of NiTi instruments this was performed by alternating different tapers and tip diameters to proceed in corono-apical direction.

An instrument with low cutting efficiency tends to have a lower ability to remove dentin when working on a wide surface, consequently requiring a high rotational **torque**. When this force exceeds the axial torsional resistance of the file, it might lock in the canal (**taper-lock**), undergo deformation and, if the rotation force is not interrupted, result in fracture. That is why both the technique put forth by Talbot with rudimentary rigid and inefficient steel files, and the techniques applied to first generation NiTi files, aimed to divide the cutting area into sectors, proceeding from the most coronal to the most apical region. This called for frequent changes in file size and taper, in order to alternate the contact areas with the root canal walls. Large sized and tapered instruments, such as orifice shapers (2.9), needed to be used for the approach to the coronal and middle areas; these instruments, usually shorter than those used up to the working length, are intended to carry out the work traditionally performed with Gates-Glidden drills in the initial stage of root canal enlargement. However, this type of instrument, although made of NiTi, maintains a certain degree of rigidity which, together with the low cutting ability determined by the still "rudimentary" design, showed the tendency to make it difficult, or even impossible in certain cases, to advance towards the working length.

This often forces the clinician to apply high pressure in the apical direction, which may lead to deformation and fracture of the instrument or to iatrogenic damage such as ledges and perforations.

The evolution of design has made it possible to use thinner and more efficient NiTi instruments, which are able to withstand engagement over much larger areas of the canal. Indeed, the thin instrument advancing in the canal maintains the patency and trajectory of the canal itself while creating an enlargement in the coronal area, where the sections increase thanks to the increased taper. This approach to preparation, described more in detail in Chapter 5, was introduced thanks to the genius of an Italian endodontist, Professor Vinio Malagnino. His experience in the use of mechanical instruments led to the design of a set of instruments that in the early 2000s differed from the mainstream, but which revolutionised endodontics worldwide and the subsequent way in which NiTi instruments were designed. Switching to a thinner, more flexible design, with greater cutting efficiency, allowed these instruments to be used with an approach that was defined as "simultaneous" or **simultaneous technique** by the inventor, while internationally it has been referred to as *single-length technique* (38,39). The sequence entails the use of smaller instruments at the beginning of preparation, which gradually advance from the coronal area to the working length. The gradual increase in tip size and taper of the instruments in this sequence means that the blades of each subsequent instrument have a limited impact on the dentin wall, resulting

2.9 Different types of instruments for orifice opening – usually with a very high taper, shortened working part compared to the ISO standard and shorter total length.

in each instrument being subject to lower torsional stress. Intuitively, in a dimensionally "small" canal, a "small" instrument is subject to less stress than a "large" instrument. This is obviously possible thanks to the remarkable cutting ability of these instruments, both in rotation and in lateral action, through the so-called **brushing** motion (40,41). The possibility of the brushing motion is also linked to the design evolution of the instruments (42). Instruments with low cutting efficiency do not withstand lateral pressures and must be used on limited contact areas, as already described, and only with a **pecking** motion, i.e. a mechanical action in which the axial pressure exerted by the operator on the handpiece produces an engagement of the rotating blades, which undergo torsional stress at the point of transition between the portion engaged in the canal and the one free to rotate. When cutting the dentin where the rotating blades are engaged, the instruments cause **reaming**, i.e. circular enlargement of the canal. In the first techniques introduced on the market, operators were recommended to only exert axial, "back and forth" motions, accurately avoiding lateral pressure (43). However, thanks to the improved cutting efficiency of instruments and following the path set by Professor Malagnino and his intuitions, the most recent techniques are based on the possibility of performing also lateral cutting by outward motions from the canal, precisely referred to as brushing. The great advantage of the brushing action consists in canal enlargement being performed without any torsional stress acting on the axis of the instrument, since it is used with outward paintbrush motions and is never engaged in the canal at this stage. In fact, the blades cut the dentin due to the force exerted by the operator in the lateral direction, even if the instrument is smaller than the canal, with virtually no risk of deformation by torsion.

The current trends in the field of rotary instruments, in almost all the sequences proposed on the market, entail the use of small-sized instruments in the initial steps of the treatment and a subsequent gradual increase in terms of tip size and taper. A decreasing number of systems still require an operational sequence that uses a pure crown-down technique. We will go back to this topic during the step-by-step description of the basic canal preparation with NiTi instruments in Chapter 5; however, we underline how the remarkable evolution in instrument design, using the same materials, has led to a drastic increase in the safety of use, predictability of the results and treatment time.

In addition to the significant changes in the design of NiTi instruments providing the advantages previously discussed, the other two main fields on which research and development efforts have focused in the last 20 years concern metallurgy and heat treatments of the NiTi alloys and the type of mechanical movement with which the instruments are used in the canals. These two topics will be described in detail in the next chapter of this book. The following chapters will analyse the strengths and weaknesses of the various systems on the market and their clinical application, in the critical and scientific opinion of the Authors, to give the reader the ability to adapt techniques and instruments to several clinical needs and therapeutic indications.

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