5 Root Canal Debridement and Disinfection in Minimally Invasive Preparation

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5.1 Introduction

Mechanical and chemical cleaning has been the hallmark of pulp canal space debridement for several decades. Historically, access convenience form has been advocated in order to obtain improved visualization and direct access of the mechanical instruments to the apical third. These concepts have been redefined with the introduction of operating microscopes, cone-beam computed tomography, and heat-treated nickel-titanium alloys. Access through magnification avoids the removal of unnecessary cervical tooth structure during endodontic procedures and super elastic alloys do not rely on straight-line access to shape root canal curvatures. Although these clinical advantages are intuitive, not all of them have been researched extensively from the basic science or the clinical research point of view. The aim of this chapter is to present the current information available in the literature on the irrigation of minimally invasive root canal preparations and to discuss the challenges of this concept to improve the prognosis of root canal treatment.

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5.2 Chemical Debridement of the Root Canal System

The goal of endodontic chemo-mechanical preparation is to remove the necrotic pulp, microorganisms, and the by-products and to generate proper conditions for the subsequent obturation [1, 2]. The ideal way to remove biofilms is by cutting and removing the affected dentin using an endodontic instrument; however, it has been demonstrated that a significant surface of the canal space is not accessible to the mechanical action of endodontic instruments due to the complex geometry of the root canal space [3–6] (Fig. 5.1). In order to improve the cleaning of these anatomical irregularities such as lateral canals, apical deltas, fins, isthmuses, and other non-instrumented areas, the original anatomy of the root canal space must be modified by increasing the natural taper of the main canal. This procedure allows the placement of endodontic instruments into the apical third, improves the flowability of the antimicrobial solutions, and facilitates the placement of intracanal dressings and filling materials, subsequently creating the conditions for healing.

Endodontic infections are polymicrobial and include the presence of facultative and anaerobic bacteria arranged in several layers of cells; these bacterial communities are known as biofilms [7–9] (Fig. 5.2). Clinical studies have shown that the mechanical instrumentation process using distilled water is able to remove the bulk of infected tissue without the use of antimicrobials in teeth with simple anatomy [10]; however, the procedure is not consistent requiring several visits. In addition, without the use of an antimicrobial medicament, bacteria can repopulate the root canal system in a matter of days or weeks. Due to these characteristics, nonspecific strong antimicrobials are necessary. Irrigant solutions can have the ability to disrupt the biofilm architecture, remove or inactivate virulence factors, and dissolve the necrotic pulp from the root canal space [11–14]. The main challenge for minimally invasive endodontic procedures is improving the debridement of the root canal space while decreasing the size of the access and the size of the preparation.

Endodontic irrigant solutions are critical for decontamination of the canal space. Sodium hypochlorite (NaOCl) is the most widely used

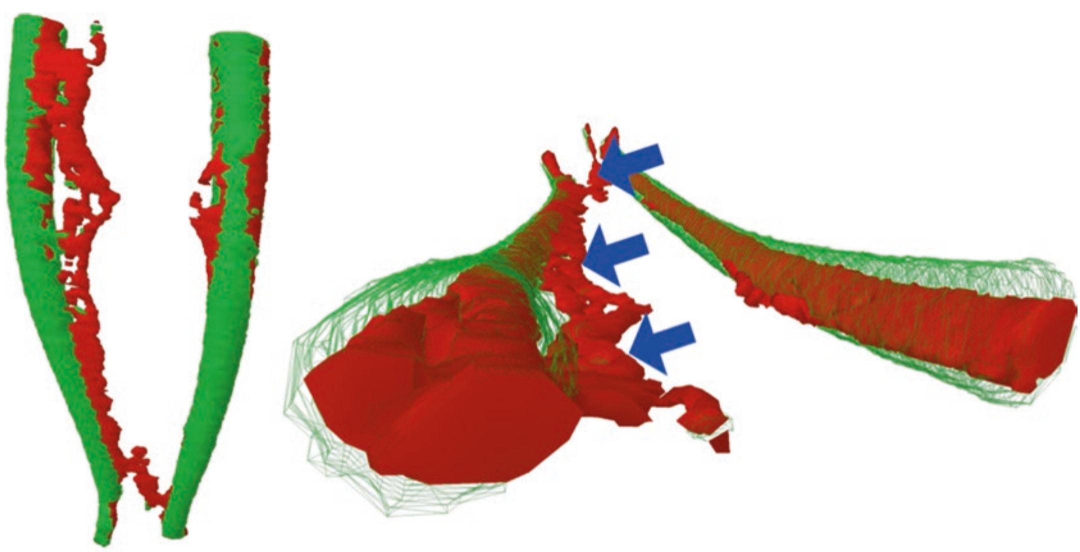

Fig. 5.1 Micro-computed tomography reconstruction of a mesial root of mandibular molar instrumented using nickel-titanium instruments. The pre-operative anatomy is highlighted in red and the removed dentin in green. Several non-instrumented areas can be observed (blue arrows). It can be also observed that the pre-operative anatomy dictates the amount of mechanical removal of the root canal dentine

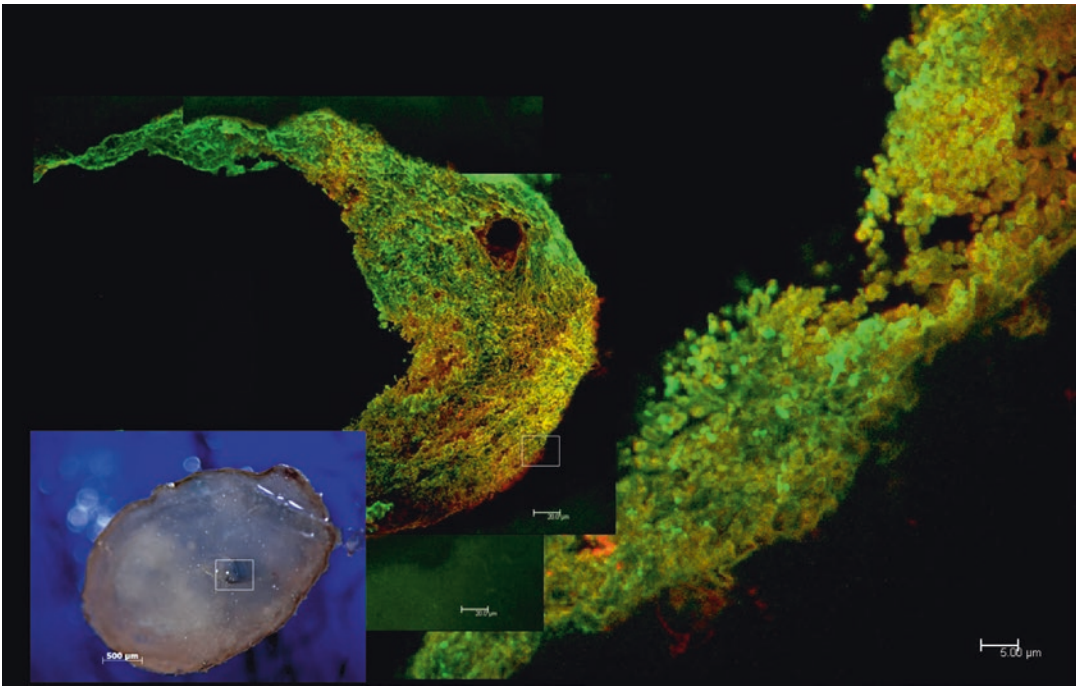

Fig. 5.2 Confocal laser scanning microscopy of a necrotic tooth root canal space (Syto 9 Propidium iodide staining). An organic layer attached to the root canal wall can be observed. A high magnification microphotograph shows a dense biofilm attached to the dentinal walls (right)

solution for root canal disinfection purposes [13]. Its properties include strong antimicrobial activity against both planktonic bacteria and biofilms and presents a unique ability to dissolve organic tissue and endotoxins from necrotic canals [12]. From a chemical point of view, the effectiveness of the NaOCl reaction depends on several factors such as concentration, exposure time, volume, temperature, refreshment rate, and ultrasonic activation among others [2, 15–17]. It is important to note that the root canal space can contain inactivators that are able to reduce the amount of available chlorine; these inactivators are dentin debris, bacterial cells, organic material as pulp tissue, blood, and inflammatory exudates [18]. One limitation of NaOCl has been recognized: it does not remove the smear layer, which allows the compaction of dentin debris against fins or isthmuses (Fig. 5.3). As mentioned before, dentin debris may physically limit the distribution of NaOCl into these areas, thereby inactivating its antimicrobial activity and consequently decreasing its effectiveness [18, 19]. Thus, the use of ethylene-diamine-tetraacetic acid (EDTA) after the decontamination procedures is also recommended for the elimination of inorganic debris before the obturation step [20]. The combination of irrigants mentioned above enhances chemical debridement during endodontic treatment.

In a classic study, Baumgartner and Mader [21] observed that pulp remnants on non-instrumented canal walls of maxillary premolars were completely dissolved by chemical means using 2.5% NaOCl. In the same way, direct contact test experiments have proven that biofilm can be successfully decontaminated and removed from the dentin structure using this agent without the use of mechanical instruments; this effect was observed even using the 1% NaOCl concentration [2] (Fig. 5.4). These findings suggest that mechanical instrumentation can be avoided if an antimicrobial and proteolytic irrigant solution like NaOCl can be delivered and evacuated in an effective way throughout the root canal space.

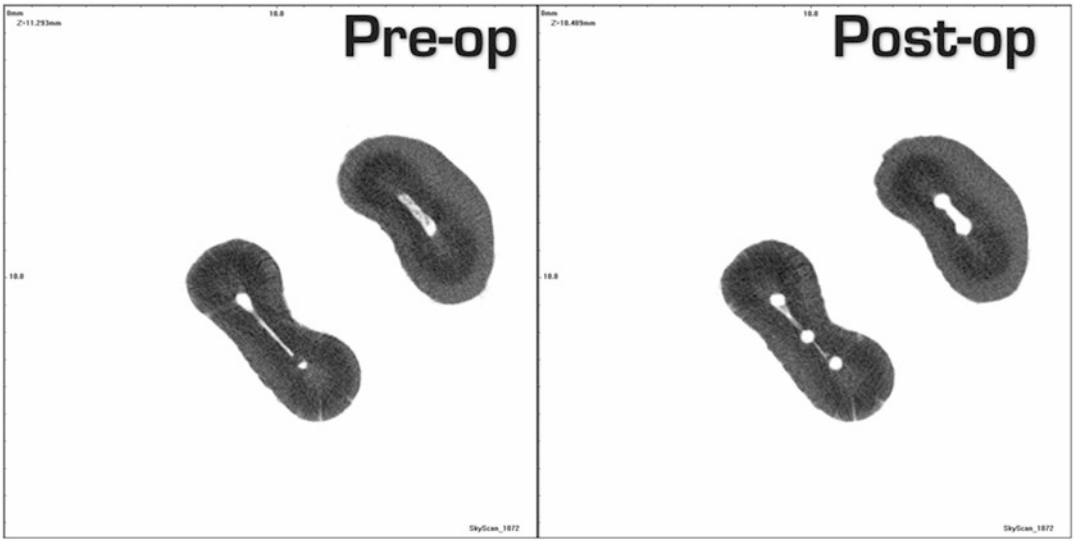

Fig. 5.3 Micro-computed tomography cross-sections at the mid-root level of an extracted mandibular molar with three canals in the mesial root before (left, pre-op) and after (right, post-op) the mechanical instrumentation of the root canals using only syringe irrigation without any activation. To note the accumulation of hard tissue debris in the isthmus and lateral communications among the three mesial root canals in the post-op cross-section. Courtesy of Gianluca Plotino, Rome, Italy

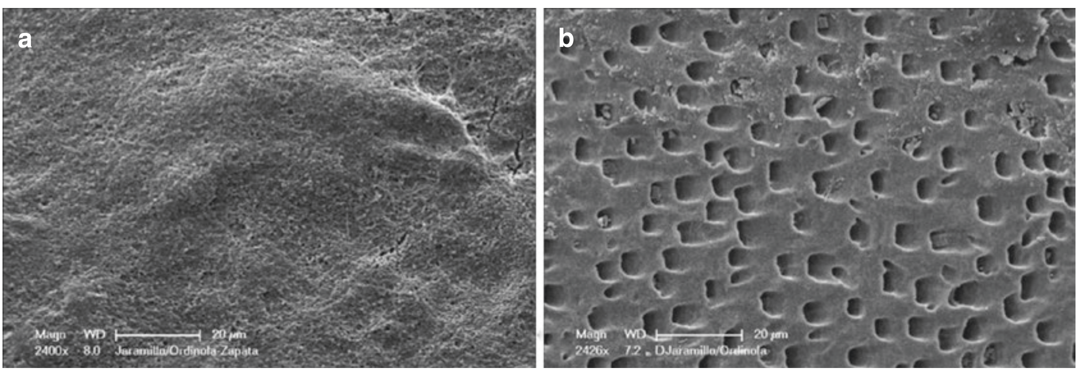

Fig. 5.4 Scanning electron microscope image of an intra-orally infected dentin. A dense contamination can be observed in (**a**). After 5 min of treatment with 5.25% sodium hypochlorite, detachment of the bacterial biofilm is observed, most of dentinal tubules are patent, and minimal amount of debris in the intertubular dentin is present (**b**)

However, several challenges are faced during the irrigation of a minimally shaped canal. Irrigant solutions present a chemical effect: the active compound of NaOCl is the free available chlorine (hypochlorite ions and hypochlorous acid) and those molecules are consumed as the solution reacts with the pulp and other intracanal organic substances, indicating that it has an instable and limited effect [18, 22]. In order to keep the concentration constant, a large volume of irrigant is used to refresh and maintain the effectiveness of the NaOCl solution. The action of irrigation also produces a mechanical effect and forces are applied by the irrigant's flowability capacity [23, 24]. The movement and subsequent cleaning produced by the NaOCl fluid can also be increased in the root canal system by sonic, ultrasonic, or laser-activated irrigation [17, 25]. These methods can create contact between active chlorine molecules and organic tissue or biofilms. To date, little information regarding the ideal taper to use these irrigation devices is found in the literature. Sodium hypochlorite is usually delivered by a syringe and a 30-gauge needle. It is accepted that irrigant exchange can happen at the apical third if the needle is placed at 1 mm from the working length [26]; due to the needle dimensions, the apical third needs to be enlarged until size 0.30 or 0.35 mm. From a technical perspective, minimally invasive endodontic procedures can restrict the flow of the irrigant solution to the apical third, and, therefore, other clinical factors need to be addressed before executing a minimally invasive preparation.

5.3 Clinical Factors and Minimally Invasive Cleaning and Shaping Procedures

Two systematic reviews have addressed the ideal master apical file size required for healing outcomes [27, 28]. The authors concluded that a large instrumentation size may be beneficial for the healing of apical pathosis in teeth with necrotic pulps and periradicular lesions. However, like many systematic reviews in endodontics, the authors stated that limited evidence was available. To date, it is not possible to define the "optimal" master apical size for teeth with vital or necrotic pulps. Several factors can affect the chemical and mechanical debridement of the root canal space and it is the clinician's decision to determine the taper and diameter necessary for the canal debridement in every particular case. Some factors are purely related to the anatomical characteristics of the tooth such as age, curvature, root canal diameter, presence of danger zones, presence of isthmuses, or the transversal cross-section of the root canal space. Other factors are related to the presence of infection or a pathological process, such as the presence of an infected pulp or the presence of internal or external root resorption.

Pulp changes can also be associated with the aging process; age-related changes such as a decrease in dentin permeability, a decrease in cell density, and the constant odontoblastic activity can lead to the presence of calcified pulp chambers. The decrease in the volume of the root canal space due to the increase in dentinal thickness can lead to the presence of calcified canals [29]. Taking this into account, it may be more difficult to debride a mandibular molar in a child or a young adult which may contain a large volume of necrotic tissue and a consistent amount of hard to reach areas compared to an elderly patient with a reduced amount of organic tissue, narrow and calcified canals, and less permeable dentin. On the other hand, irrigants may flow more efficiently in bigger canals and consequently reach inaccessible areas better compared to tight and constricted root canals.

The apical diameter is an important topic often discussed in the literature. The apical third is the critical area for therapeutic reasons; it is in close proximity to the periodontal ligament and the alveolar process. Additionally, it is the most challenging area to disinfect. A series of studies have highlighted the importance of proper apical enlargement for the decontamination of the root canal system [30, 31]. However, one limitation of the endodontic literature regarding this topic is that current studies on root canal apical diameters did not include the age variable in the study design. For example, the median of the apical diameter reported in mandibular incisors presenting a single canal is 0.36 mm [32]; however, the data was widespread distributed and apical diameters ranged approximately from 0.10 to 0.80 mm. In another study [33], the apical anatomy of 60 mandibular molars was measured, the apical analysis at the 1 mm level was reduced to only 19 samples due to the presence of large fins and isthmuses connecting the two mesial canals and the authors found that the average apical diameter was close to 0.35 mm with ranges of 0.20–0.70 mm. Although it is debatable whether these differences should be attributed to the root canal configuration or age, other studies have determined that the complexity of lateral anatomy, including the presence of isthmuses, decreases with age [34].

Curvatures also play a role during the apical diameter selection and subsequent instrumentation and irrigation. The role of root canal curvature and its association to instrument separation is not a common modern problem when compared to the literature found in the previous decades [35]. Nickel-titanium instruments, especially those that are heat-treated and reciprocating, have been demonstrated to present enough flexibility and fatigue resistance to manage difficult curvatures with rare occurrences of separation [35]. However, clinicians should be aware of the amount of dentin that is removed at the cervical level during the instrumentation of severely curved canals or "S"-shaped canals [36]. The delicate balance that exists between the shaping of the canal system and the decrease in dentinal thickness at the cervical level in teeth with severe curvatures needs to be addressed in the future.

The pathological conditions of the periapex and associated structures should also be considered. Several clinical signs can suggest the presence of a long-standing or an aggressive infection such as teeth with furcation involvement, lateral root lesions, and non-circumscribed radiolucencies. These signs could suggest an increase in the virulence of the microbiota of a root canal system, an immunocompromised patient, or a combination of both situations. Another inflammatory condition is internal apical resorption. This pathological process is associated with the presence of apical periodontitis [37]; in this scenario, the size of the last apical millimeters is modified by the pathological process increasing the diameter necessary for the debridement of this critical zone. This scenario is opposite to the presence of a necrotic tooth in an asymptomatic patient with minimal periapical changes and calcified canals. In both situations, clinical judgment is important to determine the dimensions necessary to obtain a proper irrigation and decontamination of the root canal space.

As already discussed in Chap. 3, anatomical evidence of root canal diameters in the apical third of both physiologic and pathologically resorbed situations suggests that anatomical enlargement of the apical third should be performed to control infection and reduce the presence of debris and remnants in this area. Studies have demonstrated that apical enlargement is required to obtain cleaner root canals in the apical third, but enlargement is not needed to obtain clean canals in the middle and coronal thirds [38]. In fact, increasing the taper of the preparation does not appear to have further influence on canal cleanliness [39, 40]. On the other hand, when considering the middle and coronal third of the root, a recent study has demonstrated that, if a proper irrigation activation technique is used, root canals may be cleaned even in root canals instrumented using a minimal taper of preparation such as 20/0.04 or 25/0.04 [41].

As a consequence, a minimally invasive instrumentation that is respectful of pericervical dentin may be carried out in specific situations with low taper instrument while still allowing for cleaning in the coronal and middle thirds. Minimally invasive instrumentation can increase apical diameters of instrumentation as large as necessary to promote healing without increasing taper of the basic preparation.

5.4 Chemical Cleaning of the Pulp Chamber

One of the key clinical challenges in this context is the lack of definition of a conservative or ultraconservative access. While it is well accepted that the main purpose of an access cavity is to gain straight-line access to the root canal system, it should also facilitate optimal debridement of the access cavity itself. This implies that the access design should not impede disinfection. The modern access cavity designs recommend preservation of coronal and pericervical tooth structure, without complete de-roofing of the pulp chamber, to enhance the structural integrity of the tooth [42]. One access cavity design where the chamber floor may be subject to compromised debridement is the orifice-directed dentin conservation access or the "truss" access. In this design, cavities are prepared to approach the mesial and distal canal systems in a mandibular molar while for maxillary molars, the mesio- and disto-buccal canals are approached through one cavity and the palatal canal through another [43].

A recent study [44] investigated the debridement of the pulp chamber, the mesial root canals, and the isthmus between the mesiobuccal and mesiolingual root canals of mandibular first molars after preparing access cavities of two designs: the traditional access and the “truss” access. Root canals were prepared to the same dimensions (30/0.06) in all the specimens, using 3% of sodium hypochlorite as the irrigating solution. The experiment was performed on vital molars extracted for periodontal reasons. Using a histological analysis, the percentage of remaining pulp tissue was calculated at the pulp chamber, coronal, middle, and apical thirds of the root canal, and the isthmus region. The pulp chambers were found to house significantly less remaining pulp tissue in the teeth where traditional accesses were prepared (Fig. 5.5). Interestingly, the isthmus and the root canals did not show any significant differences in the percentage of remaining pulp tissue with either access cavity design.

These results have a certain clinical implication such as the debridement of chamber canals and furcation canals have been described in the literature [45, 46]. These portals may serve as a source of continued nutrition to bacterial biofilms that remain within root canals, contributing to the persistence of post-treatment disease. Similarly, in an infected root canal system, egress of microbial biofilms and toxins into the furcal region can initiate periodontal breakdown secondary to endodontic disease. An important consideration in this work was that irrigation was performed only with a syringe and needle. Given the results obtained in vitro by different irrigant activating systems [47], it may be assumed that activated irrigation may result also in cleaner pulp chambers and root canal systems regardless of the access cavity design.

5.5 Minimally Instrumentation and Irrigation Procedures

In some cases, root canals of single-rooted teeth are naturally tapered; a good example is a tooth with an history of dental trauma and arrested tooth development and incomplete root wall formation. In this particular case, the disinfection strategy is supported by minimal instrumentation and the use of antimicrobial solutions and intracanal medicaments to reduce the microbial load. Current research has focused on answering the

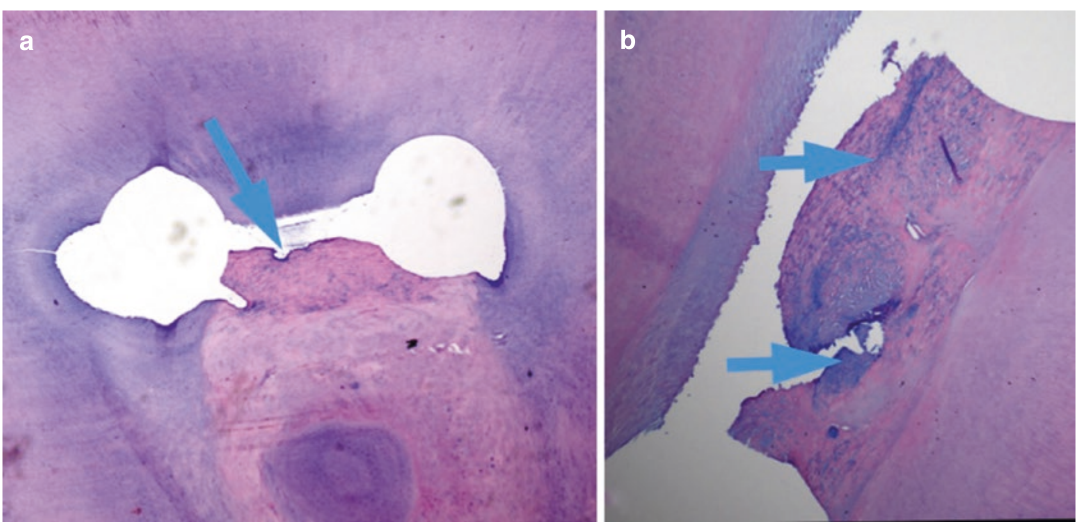

Fig. 5.5 Histological section of the pulp chamber of a mandibular molar after minimally invasive access and sodium hypochlorite syringe irrigation (**a**, **b**). Remaining organic tissue can be observed between the mesial canals (blue arrow)

question: Can minimally prepared access cavities and root canals be debrided to the same extent as conventional preparations? Few studies have attempted to address this question from a biological stand point (histological or microbiological).

To date, there is substantial evidence that instruments used for root canal preparation do not contact the walls completely and these walls retain pulp tissue or debris even after root canal preparation to sizes 25 or 40 with sodium hypochlorite irrigation using a syringe and needle. Several studies have addressed this important topic in the past in order to investigate the effect of root canal preparation sizes on several outcome measures including cleanliness [39, 48], microbial reduction [30, 49, 50], or healing outcome [51]. Rather surprisingly, all these studies were performed with only syringe-and-needle irrigation.

It has been shown that canals prepared to size 35, 0.04 taper with the SAF 2.0 instrument or size 30, 0.04 XP-Endo Shaper still had remnant pulp tissue (1.36% and 13.29%, respectively) in the apical third of root canals, while another instrument (TRUShape, Dentsply Sirona) with its size 30.06 preparation resulted in <0.5% residual tissue [52]. Three recent studies attempted to compare the histological cleanliness of root canals prepared to small sizes. Using a brush-based supplementary irrigant agitation technique (Finisher GF Brush, MedicNRG, Kibbutz Afikim, Israel), one study reported that oval root canals were significantly cleaner than those where the oval root canals were prepared to a size 25, 0.04 taper and irrigated with a syringe and needle [53]. In this study, root canals were prepared either with a core-less stainless-steel rotary instrument (Gentlefile, MedicNRG, Israel) or a rotary nickel-titanium instrument (EdgeFile X7, EdgeEndo, Albuquerque, New Mexico, USA). Another study [54] prepared root canals using the Reciproc R25 instrument and root canals were irrigated with sodium hypochlorite, which was then activated/agitated using ultrasonics, sonic, or manual dynamic methods. The authors concluded that ultrasonic activation resulted in significantly less pulp tissue remnants than the other methods.

The first study [55] to demonstrate the effect of activated irrigation on cleanliness of premolar canals prepared to small sizes showed that when sodium hypochlorite was ultrasonically activated the root canal cleanliness was not dependent on the apical preparation size (20 vs. 40/ 0.04 taper) (Fig. 5.6). However, when irrigated only with a syringe and a needle, root canals prepared to

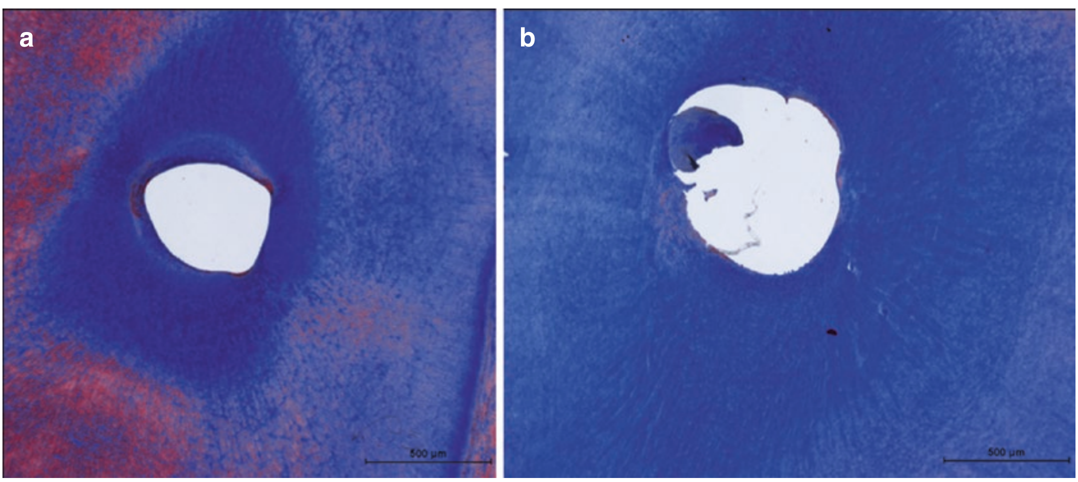

Fig. 5.6 Histological sections of the apical third of a minimally instrumented mandibular premolar (20/0.04) that was irrigated using ultrasonic activation (**a**); no remaining debris could be observed compared to the case that was irrigated without using ultrasonic activation (**b**)

larger sizes were cleaner, despite the fact that they housed substantial amounts of pulp tissue. Furthermore, these results were independent of the cross-sectional shape of the root canal (round vs. oval). The important caveat in this paper, as reported by the authors, was that 18 mL of 3% sodium hypochlorite was used per root canal. Despite this volume, root canals retained significant tissue remnants when irrigated with a syringe and a needle. Thus far, no study has investigated the ability of minimal preparations to debride infected root canals, especially in the apical third. Until such literature demonstrates positive findings, the current evidence suggests that minimal apical preparation of root canals should be eventually limited to vital teeth and with the mandatory use of activated irrigation. In fact, it must be considered the importance of the mechanical cleaning of the root canals, especially in the apical third, when an enlarged apical preparation is performed in infected teeth. In these cases, reduction of intracanal infection through the mechanical removal of infected dentin cannot be substituted by the chemical action of irrigants.

5.6 Adjunctive Systems to Clean Minimally Instrumented Root Canals

Despite the numerous advantages of sodium hypochlorite, its ability to disinfect the root canal environment in a predictable manner has not been consistent in studies [9, 11, 14, 56]. The efficacy of this solution depends not only on its chemical effect but also on the mechanical effectiveness of the irrigation technique and the interaction with intracanal content. Conventional positive apical needle irrigation has shown limitations to improve the delivery of the irrigant solution to the apical third. Nair et al. [57] observed this fact microscopically, demonstrating that residual biofilms can be present in the accessory anatomy of mandibular molars even after instrumentation and full-strength sodium hypochlorite irrigation. In order to improve the antimicrobial and cleaning ability of the irrigation step, several supplemental irrigation techniques have been proposed.

The use of ultrasonic energy during the irrigation procedure is an accepted step to improve the cleaning and disinfection of the root canal space. Ultrasonic activation of the irrigant solution for 1 min using three cycles of 20 s appears to be an accepted time for the final irrigation step [58]. The effectiveness of the ultrasonic irrigation is determined by its capability to create “cavitation” and “acoustic streaming” [58]. Previous researchers have demonstrated that sodium hypochlorite activation enhances the effectiveness of organic tissue dissolution [59], improves the removal of calcium hydroxide medicament [60], increases the removal of hard tissue debris [25], and facilitates the final cleaning during retreatment procedures [61]. Most of these benefits have been confirmed in bench top studies, but at this time, ultrasonic irrigation has not been demonstrated to improve the healing rate of apical periodontitis [62] (Fig. 5.7).

In order to increase the effectiveness of chemical intracanal cleaning, several other systems have been introduced over the years. The EndoVac system (Discus Dental, Culver city, USA), for example, uses apical negative pressure to promote the flow of the irrigant solution placed into the pulp chamber to the apical third of the root canal where the tip of a microcannula is placed. Apical instrumentation to a minimum size of 0.35 mm must be achieved to ensure the microcannula tip (0.32 mm) reaches the apical third. Satisfactory cleaning efficacy at the apical third of extracted teeth with vital pulps in comparison to classic needle irrigation was observed using this system in teeth with simple and complex anatomy [63, 64]. Despite the different mechanism of action of passive ultrasonic irrigation and the EndoVac system, research has shown similar results for the elimination of hard tissue debris [65, 66] and ability to deliver the irrigant solution to the working length [67].

The Lussi’s non-instrumentation technique [68, 69] probably represented the first attempt for an actual minimally invasive cleaning of the root canals system. The advantages of the non-instrumentation technique were published in

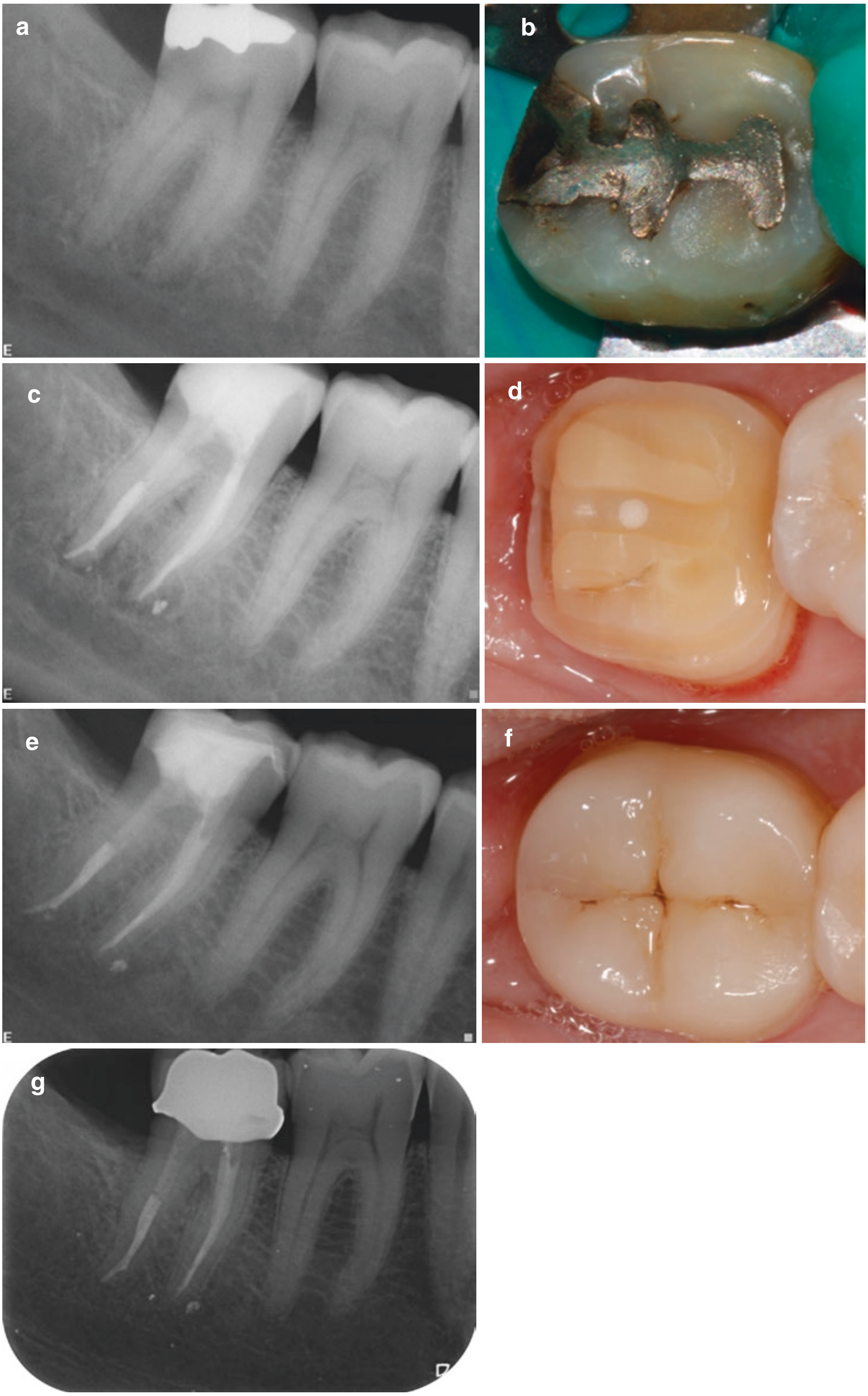

Fig. 5.7 Pre-operative radiograph (**a**) and image (**b**) of a lower right second molar with a caries penetrating the pulp chamber and periapical lesions in both the mesial and distal roots; post-operative radiograph (**c**) and image (**d**) after endodontic treatment and post reconstruction; 5-years radiographic (**e**) and clinical (**f**) control and 10-years radiographic control (**g**), showing the complete resolution of the periapical lesions. (Courtesy of Gianluca Plotino, Rome, Italy)

1993 [69], and, according to its developer, the system was able to create hydrodynamic turbulence and controlled cavitation (25 Hz). Exchange of the irrigant solution (NaOCl) was accomplished using a double tube model. Injection of the irrigant fluid was in the outer tube, while the reflux occurred in the inner tube. The tooth had to be isolated to achieve reduced pressure. This allowed cleaning of the canal system in 10 min independently of the number of root canals presented in the case. The non-instrumentation technique did not recommend the use of hand or rotary instruments. Despite its promising in vitro results, a clinical evaluation of 22 teeth treated by the non-instrumentation technique and extracted after the therapy showed a significant amount of organic debris at the middle and apical third [70].

Following some concepts of the Lussi technique, the GentleWave system (Sonendo, Orange, CA, USA) attempted to propose a novel irrigation system to clean the root canal system after a minimal instrumentation [71–74]. It is based on several principles that include degassing of the irrigant solution, the use of negative pressure, circulation of a fluid in a close circuit, the use of sound waves below and above the ultrasonic spectrum that can propagate the degassed fluid to reach remotes areas of the root canal space, and the use of tissue dissolving agents such as sodium hypochlorite and EDTA. The GWS is able to generate negative pressure [73] in part due to the "closed-loop" system created with a resin platform built by the clinician that serves as a gasket between the tooth and the handpiece. After platform creation, the system delivers high-speed streams of irrigants through a handpiece. The manufacturer of the GentleWave system recommends maximal preservation of the tooth structure so that the suggested dimension of the preparation is a size 20/0.06 taper. According to the manufacturer, contraindications to using the device are resorption, perforations, open apices, and roots adjacent to anatomical structures such as the maxillary sinus or the inferior alveolar nerve. These contraindications may be due to concerns about irrigant extrusion.

During the irrigation process of this system, the irrigant streams collide with a concave plate at the terminus of the handpiece, which is positioned 1 mm or more occlusal to the pulpal floor. After collision with the plate, the irrigants are deflected around the chamber and into the root canals producing a cavitation cloud. Fluid circulation helps replenish reactants and remove by-products from the root canal system, thus increasing the tissue dissolution rate [71]. Additionally, refreshment is important since bubbles may form and stay at the chemical reaction site and may act as barriers impeding fresh reactants reaching areas such as isthmuses and fins. However, except for one report [72], no study has examined the efficacy of debridement using this system with a minimal instrumentation size. In this study, authors treated extracted human molars instrumented until a 15/0.04 apical size and the GentleWave protocol was compared to the conventional instrumentation and irrigation technique. The results showed that the minimal instrumentation technique was able to clean the canal space significantly better than the conventional irrigation group [72].

A recent debris removal analysis [74] using microCT imaging revealed that accumulated hard tissue debris removal was enhanced with the GentleWave when compared to continuous ultrasonic irrigation (ProUltra PiezoFlow, Dentsply Maillefer; Charlotte, NC); however, there was no difference between the GentleWave and intermittent, passive ultrasonic irrigation (Irrisafe wire, Satelec, Bordeaux, France). Although minimal evidence exists concerning the efficacy of the GentleWave, the device appears to have the ability to debride minimally prepared root canal systems (Fig. 5.8).

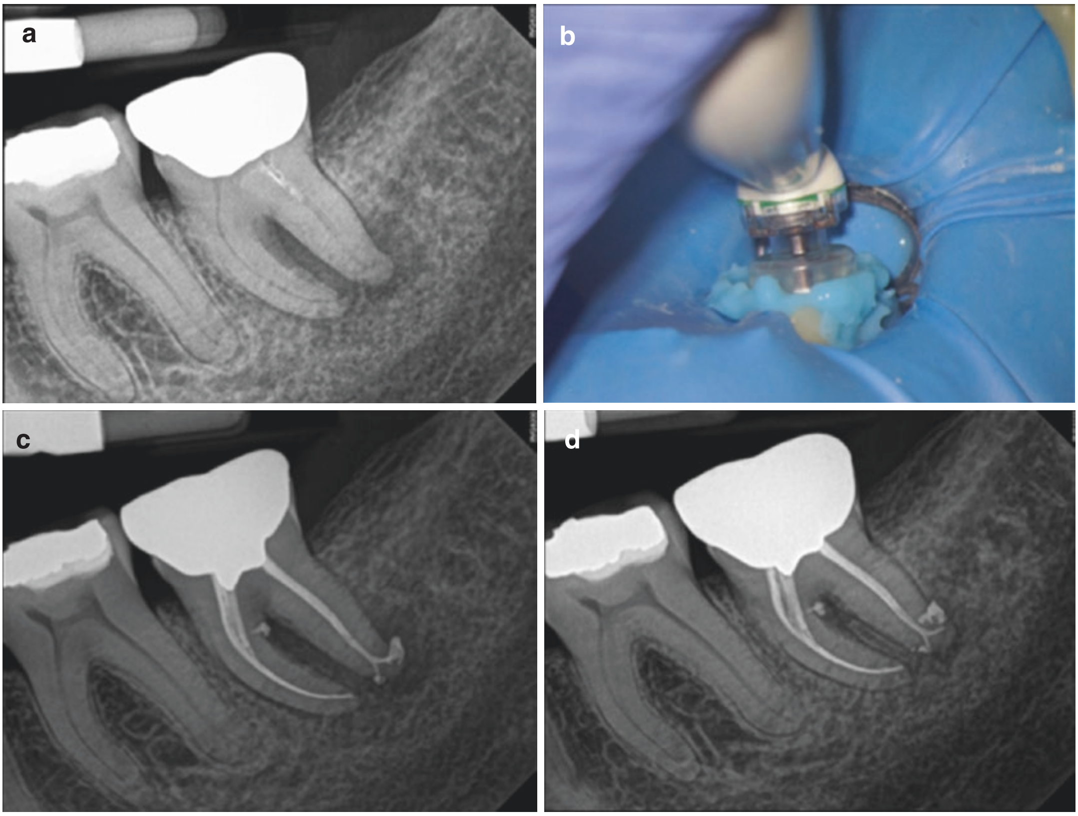

Fig. 5.8 (**a**) Mandibular second molar diagnosed with a previously initiated treatment and asymptomatic apical periodontitis. The root canal was minimally instrumented and irrigated with 500 mL of irrigant solution using the Gentlewave system; the resin platform for the use of the irrigation handpiece can observed in (**b**). Immediate obturation shows the presence of accessory anatomy at the furcation and apical level (**c**). A 3-month follow-up shows that the healing is in process (**d**)

5.7 Concluding Remarks

The disinfection of root canal systems has traditionally been achieved physically, through instrumentation and chemically, through the use of irrigating solutions. Achieving the goal of complete debridement within the root canal space while conserving tooth structure is a delicate balance. Enlarging root canal systems to improve mechanical and chemical debridement can reduce the microbial load present. On the other hand, this enlargement has the potential to structurally weaken teeth due to dentin removal. Modern endodontic research and technology in irrigation have allowed the specialty to explore the long-term preservation of teeth through minimally invasive approaches, or better defined "anatomically invasive approach." This concept means that clinicians can be minimally invasive when possible (i.e., maintain a low taper in the middle and coronal thirds when root canals are originally constricted and with no or minimal taper), while enlarging the canal when anatomy dictates (i.e., apical diameter of preparations needed to touch circumferentially the root canal walls in the apical third) and to activate irrigants and/or use innovative cleaning systems in minimally instrumented canals.

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