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Lasers in endodontics

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With the rapid development of laser technology, new lasers with a wide range of characteristics are now available and being used in various fields of dentistry. The search for new devices and technologies for endodontic procedures always has been challenging. In the past 2 decades, much experience and knowledge has been gained. The purpose of this article is to provide an overview of the current and possible future clinical applications of lasers in endodontics, including their use in alleviating dentinal hypersensitivity, modification of the dentin structure, pulp diagnosis, pulp capping and pulpotomy, cleaning and shaping of the root canal system, and endodontic surgery. Endodontic procedures for which conventional treatments cannot provide comparable results or are less effective are emphasized.

Dentinal hypersensitivity and modification of the dentin structure

Dentinal hypersensitivity is characterized as a short, sharp pain from exposed dentin that occurs in response to provoking stimuli such as cold, heat, evaporation, tactility, osmosis, or chemicals [1]. Such pain cannot be ascribed to any other form of dental defect or pathology [2]. Erosion, abrasion, attrition, gingival recession, periodontal treatment, and anatomic defects have been suggested as possible risk factors for dentinal hypersensitivity [3–5]. It is estimated that one in seven patients suffers from some degree of dentinal hypersensitivity [5]. Some studies show an even higher

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prevalence [6,7]. The wide variation in the reported prevalence may be related to cultural or genetic factors or to experimental variations in the methods of assessment or sampling [8]. The cervical region of incisors and premolars tends to be the most affected, often on the side opposite the dominant hand. This finding is consistent with toothbrush abrasion as an etiologic factor [8]. Dentinal pain is elicited by cold stimuli in up to 90% of patients, although mechanical and chemical stimuli also are effective [9]. Brannstrom et al [10,11] proposed that nerve endings in the dentin–pulp border area are activated by hydrodynamic fluid flow in response to dentinal stimulation (the hydrodynamic mechanism). According to the hydrodynamic theory, rapid dentinal fluid flow serves as the final stimulus in activating intradental nociceptors for many different types of stimuli. Studies have confirmed that the patency of the dentinal tubules is a prerequisite for the sensitivity of exposed dentin [12–14]. It also was shown using scanning electron microscopy (SEM) that teeth with dentinal hypersensitivity have a significantly higher number of patent dentinal tubules per millimeter [2] and a significantly greater mean diameter per tubule than control teeth [14]. The management of dentinal hypersensitivity involves the application of therapies that reduce the flow of dentinal fluid or lower the activity of dentinal neurons [15]. Seventy years ago, Grossman [16] outlined the requirements for the treatment of this condition: therapy should be nonirritating to the pulp, be relatively painless on application, be performed easily, act rapidly, be effective for a long period of time, be devoid of staining effects, and be consistently effective.

Some clinical interventions aimed at blocking dentinal fluid flow have been reported to have a positive effect in reducing dentinal hypersensitivity. They include application to exposed dentinal tubules of resins [17,18], oxalate salts [15], isobutyl cyanoacrylate [19], and fluoride-releasing resins or varnishes [20], and the use of devices that burnish exposed dentin [21]. The use of desensitizing agents to reduce neuronal responsiveness to dentinal stimuli also has been investigated extensively. It was reported that potassium-containing dentifrices [22,23], fluoride-containing medicaments [24,25], and agents containing 10% strontium chloride [26] were partially effective in reducing dentinal hypersensitivity.

It should be mentioned that many studies are simply before-and-after comparisons, and the lack of direct comparisons and systematic evaluations makes it difficult to determine which of the proposed treatment regimens offers the greatest efficacy and duration with the least adverse effects [8]. It seems that to date, most of the reported therapies have failed to satisfy one or more of the requirements for the treatment of dentinal hypersensitivity [2] as recommended by Grossman [16] and, obviously, research in this important therapeutic area is in progress.

A different treatment modality for reducing dentinal hypersensitivity involves the use of laser technology. The rationale for laser-induced reduction in dentinal hypersensitivity is based on two possible mechanisms that differ greatly from each other. The first mechanism implies the direct effect of laser irradiation on the electric activity of nerve fibers within the dental pulp, whereas the second involves modification of the tubular structure of the dentin by melting and fusing of the hard tissue or smear layer and subsequent sealing of the dentinal tubules.

The lasers used for the treatment of dentinal hypersensitivity may be divided into two groups: low output power lasers (helium-neon and gallium/aluminum/arsenide [diode]) and middle output power lasers (Nd:YAG and carbon dioxide [CO_2]) [2]. Kimura et al [27,28] initially used low output power laser therapy to support wound healing. The anti-inflammatory effect [29] of this delivery system and its ability to stimulate nerve cells in a clinical environment also has been described [30,31]. Senda et al [32] were the first to apply the helium-neon laser in treating dentinal hypersensitivity. They used an output power of only 6 mW, which does not affect the morphology of the enamel or dentin surface but allows a small fraction of the energy to reach the pulp tissue. It was reported that the effectiveness of this treatment ranges from 5.2% to 100%. Although the mechanism causing the reduction in hypersensitivity is not apparent, it was claimed that helium-neon laser irradiation affects electric activity (action potential) [30] rather than Aδ- or C-fiber nociceptors [31].

Three gallium/aluminum/arsenide (diode) laser wavelengths (780, 830, and 900 nm) were used for the treatment of dentinal hypersensitivity [2]. Matsumoto et al [33] were the first to report the use of a diode laser for this purpose. They applied an output power of 30 mW in a continuous wave irradiation mode for 0.5 to 3 min and reported treatment effectiveness ranging from 85% to 100%. The investigators considered that the analgesic effect was related to depressed nerve transmission caused by the diode laser irradiation blocking the depolarization of C-fiber afferents [34].

In 1972, Kantola [35] used a CO_2 laser to create craters in dentin. Microradiography and electron probe analysis revealed higher levels of calcium and phosphorus in the fused or recrystallized dentin walls of the crater compared with levels in normal dentin. The relative augmentation of the inorganic content was attributed to the burning off of the organic component by the laser energy. One year later, in a follow-up study using radiographic diffraction analysis, Kantola [36] observed that in the laser-irradiated fused dentin, recrystallization had occurred and the dentin had changed structurally so that it closely resembled the crystalline structure of normal enamel hydroxyapatite. The conversion of dentin into a crystalline structure following CO_2 laser irradiation also has been reported by others [37,38], but the induced effect of the carbonization of organic material along with the melting of dentin cannot be overlooked [38].

Dederich et al [39] were the first to describe the melting and re-crystallization of root canal wall dentin following Nd:YAG laser exposure. Based on the nonporous appearance of the root canal wall under SEM, they speculated that the exposed dentin exhibited reduced permeability to fluids.

Decreased permeability of laser-treated dentin caused by fusion of the smear layer into the dentinal tubules also was reported [40]. In this study, the investigators evaluated the effect of irradiation of dentin with the Nd:YAG laser, using SEM and dye penetration. Reduction in dentin permeability and melting of the apical dentin surfaces in teeth following apicoectomy also has been reported by Stabholz et al [41,42], who used Nd:YAG laser energy (3 W) to irradiate the teeth.

Moritz et al [43] used a CO_2 laser with an output power of 0.5 W in a continuous wave mode and an irradiation time of 5 seconds to treat dentin hypersensitivity. Treatment effectiveness ranged from 59.8% to 100%, and the investigators postulated that the CO_2 laser reduced dentin hypersensitivity by occluding or narrowing the dentinal tubules. Sealing of dentinal tubules and reduction of permeability can be achieved with the CO_2 laser when moderate energy densities are used [44]. There have been no reports of nerve analgesia by CO_2 laser irradiation.

It also was suggested that the Nd:YAG laser effect on dentin hypersensitivity is related to the laser-induced occlusion or narrowing of the dentinal tubules [45]. Direct nerve analgesia [46] and a suppressive effect achieved by blocking the depolarization of Aδ and C fibers [47] also were considered possible mechanisms accounting for the effect of Nd:YAG laser irradiation in reducing dentinal hypersensitivity. Renton-Harper and Midda [48] conducted a clinical trial on 30 patients to evaluate the efficacy of the Nd:YAG laser in reducing dentinal hypersensitivity. The results indicated that application of Nd:YAG laser irradiation to sensitive teeth could significantly reduce the degree of sensitivity and alleviate this condition. The reported treatment effectiveness was 90%, and the investigators concluded that the procedure could be performed easily and painlessly with a predictable response and considerable patient satisfaction. The possibility of thermal side effects, however, was not addressed.

Watanabe et al [49] recently reported the use of the erbium:yttrium-aluminum-garnet (Er:YAG) laser for the treatment of dentin hypersensitivity. A low-power laser irradiation (25 to 35 mJ per pulse) was used. Treatment effectiveness ranged from 16% to 61%. The investigators also reported that the condition could recur and concluded that low-power irradiation by Er:YAG laser is effective for dentin hypersensitivity but has some limitations. Stabholz et al [50] studied the effect of the Er:YAG laser with and without an air–water cooling spray on dentin and, using different energy levels, did not find any melting or sealing of dentinal tubules [50]. The authors, therefore, believe that any reduction in dentin hypersensitivity due to Er:YAG laser irradiation cannot be attributed to occlusion or narrowing of dentinal tubules.

The ability of other lasers to vaporize, fuse, melt, or seal dentinal tubules by recrystallization of the mineral component of dentin has been reported with varying success [51,52]. Stabholz et al [53,54] investigated the effects of excimer lasers on exposed dentinal tubules of extracted human teeth and found melting of dentin and closure of exposed dentinal tubules (Figs. 1 and 2). Such modification of the dentin surface may be accepted as a treatment modality applicable to hypersensitivity and the prevention of bacterial penetration through dentinal tubules under fillings because melting and resolidification of the dentin and the closure of the tubules may be permanent. A possible advantage in using excimer lasers could be their relative safety (ie, the lack of thermal damage to the surrounding tissues). The feasibility of introducing excimer lasers into dental offices, however, remains questionable at present, making these lasers interesting tools for research but impractical in the clinical setting.

When examining SEM photographs of dentin irradiated by lasers such as CO_2, Nd:YAG, and excimer, melting and resolidification of dentin usually is observed. A closer look frequently reveals that the melted material resembles glazed interconnected droplets. Thus, resolidification and recrystallization of

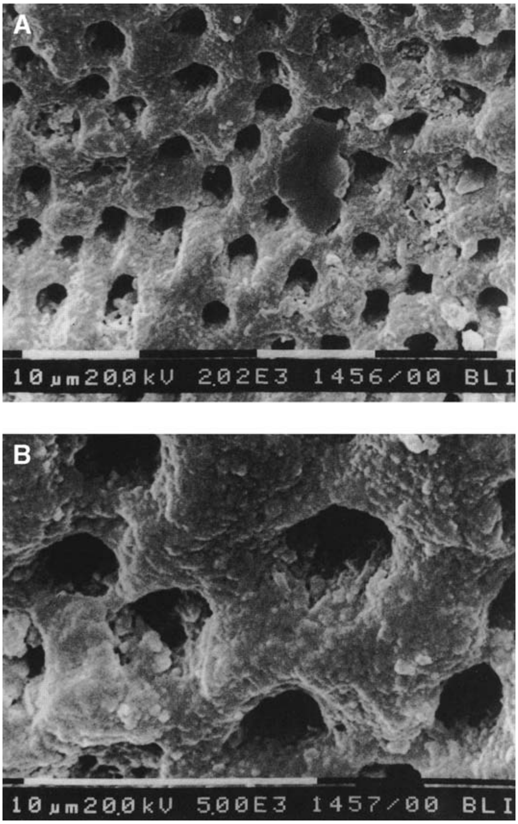

Fig. 1. (*A*) Photomicrograph of a nonlased dentin surface showing exposed dentinal tubules almost without smear layer (original magnification ×2000). (*B*) Photomicrograph of a nonlased dentin surface showing exposed dentinal tubules almost without smear layer (original magnification ×5000).

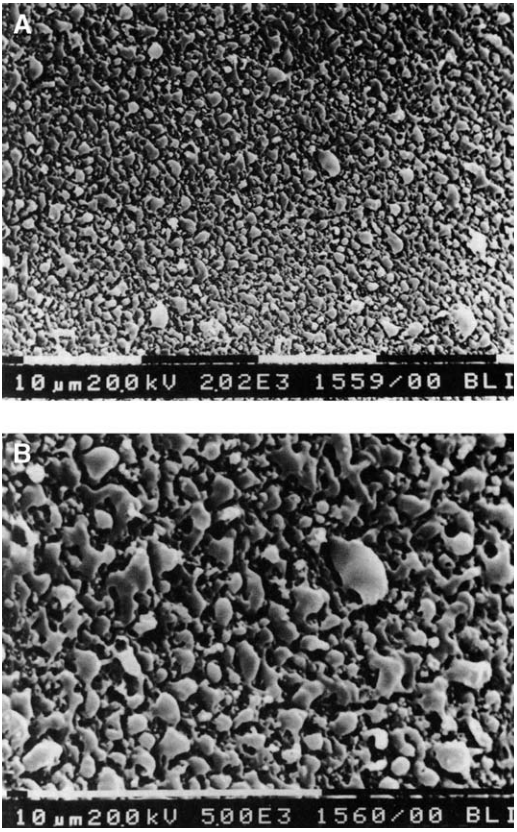

Fig. 2. Photomicrographs of lased area with fluence of 0.5 J/cm^2. (*A*) The surface is composed of finer grain of melted material spread uniformly throughout the surface (original magnification ×2000). (*B*) The same area at ×5000 magnification. Original location of tubules openings cannot be observed.

the melted areas appears to be incomplete and discontinuous. A solid, uninterrupted melted and resolidified area would likely be less permeable and could more effectively block external stimuli associated with dentinal hypersensitivity and the penetration of microorganisms into the dentinal tubules. Recent experiments on the application of 9.6-μm CO_2 laser irradiation to enamel and dentin show promising results regarding its ability to melt hard tissues of the tooth [55]. In the future, the 9.6-μm CO_2 laser could serve as an important tool in the armamentarium of a modern dental office. Its potential for dental application in dentistry merits closer attention. Efforts should be focused on the search for a laser wavelength with optimal irradiation parameters that will enable the clinician to produce ideal modification of the dentin surface and other hard tissues of the tooth. In our race to develop modern treatment modalities such as sealing dentinal tubules with lasers to reduce dentinal hypersensitivity and our effort to provide patients appreciative service, one must not forget the importance of dental pulp vitality. Complete familiarity with a safe and recommended protocol is essential at all times when irradiating vital teeth with lasers to alleviate the pain associated with hypersensitive dentin.

Pulp diagnosis

Laser Doppler flowmetry, which was developed to assess blood flow in microvascular systems [56], also can be used for diagnosis of blood flow in the dental pulp [57]. This technique uses helium-neon and diode lasers at a low power of 1 or 2 mW [58].

The laser beam is directed through the crown of the tooth to the blood vessels within the pulp. Moving red blood cells causes the frequency of the laser beam to be Doppler shifted and some of the light to be backscattered out of the tooth [57].

The reflected light is detected by a photocell on the tooth surface and its output is proportional to the number and velocity of the blood cells [59,60]. The main advantage of this technique, in comparison with electric pulp testing or other vitality tests, is that it does not rely on the occurrence of a painful sensation to determine the vitality of a tooth. Moreover, teeth that have experienced recent trauma or are located in part of the jaw that may be affected following orthognathic surgery, can lose sensibility while intact blood supply and pulp vitality are maintained [57]. It was reported that 21% of teeth in patients that did not respond to electrical stimulation following Le Fort I operations showed an intact blood supply when tested with laser Doppler flowmetry [61]. Diagnosis of the vitality of these pulps based mainly on electric pulp testing would have resulted in needless endodontic therapy.

Laser Doppler flowmetry has some limitations. It may be difficult to obtain laser reflection from certain teeth. Generally, the anterior teeth, in which the enamel and dentin are thin, do not present a problem. Molars, with their thicker enamel and dentin and the variability in the position of the pulp within the tooth, may cause variations in pulpal blood flow [56,58]. Furthermore, differences in sensor output and inadequate calibration by the manufacturer may dictate the use of multiple probes for accurate assessment [62]. Laser Doppler flowmetry assures objective measurement of pulpal vitality. When equipment costs decrease and clinical application improves, this technology could be used for patients who have difficulties in communicating or for young children whose responses may not be reliable [57].

Pulp capping and pulpotomy

Pulp capping, as defined by the American Association of Endodontists, is a procedure in which ‘‘a dental material is placed over an exposed or nearly exposed pulp to encourage the formation of irritation dentin at the site of injury.'' Pulpotomy entails surgical removal of a small portion of vital pulp as a means of preserving the remaining coronal and radicular pulp tissues.

Pulp capping is recommended when the exposure is very small, 1.0 mm or less [63,64], and the patients are young; pulpotomy is recommended when the young pulp already is exposed to caries and the roots are not yet fully formed (open apices).

The traditionally used pulp-capping agent is calcium hydroxide [65,66]; however, when it is applied to pulp tissue, a necrotic layer is produced and a dentin bridge is formed. The same may occur when the pulpotomy procedure is applied. A recently introduced material, mineral trioxide aggregate, shows favorable results when applied to exposed pulp. It produces more dentinal bridging in a shorter period of time, with significantly less inflammation; however, 3 to 4 hours are necessary for complete setting of the mineral trioxide aggregate [67–69]. The success rate of pulp capping, whether direct or indirect, ranges from 44% to 97%. In pulpotomy, the same agents are used until root formation has been completed. It is debatable whether full root canal treatment should then be initiated [70,71].

Since the introduction of lasers to dentistry, several studies have shown the effect of different laser devices on dentin and pulpal tissue. Although ruby lasers caused pulpal damage, Melcer et al [72] showed that the CO_2 laser produced new mineralized dentin formation without cellular modification of pulpal tissue when tooth cavities were irradiated in beagles and primates. Shoji et al [73] applied CO_2 laser energy to the exposed pulps of dogs using a focused and defocused laser mode and a wide range of energy levels (3, 10, 30, and 60 W). Charring, coagulation necrosis, and degeneration of the odontoblastic layer occurred, although no damage was detected in the radicular portion of the pulp. Jukic et al [74] used CO_2 and Nd:YAG lasers with energy densities of 4 J/cm^2 and 6.3 J/cm^2, respectively, on exposed pulp tissue. In both experimental groups, carbonization, necrosis, an inflammatory response, edema, and hemorrhage were observed in the pulp tissue. In some specimens, a dentinal bridge was formed.

Moritz et al [75] used a CO_2 laser in patients in whom direct pulp capping treatment was indicated. An energy level of 1 W at 0.1-second exposure time with 1-second pulse intervals was applied until the exposed pulps were completely sealed. They were then dressed with calcium hydroxide (Kerr Life; Kerr Corp., Orange, California). In the control group, the pulps were capped with calcium hydroxide only. Symptoms and vitality were examined after 1 week and monthly for 1 year: 89% of the experimental group had no symptoms and responded normally to vitality tests versus only 68% of the control group.

In cases of deep and hypersensitive cavities, indirect pulp capping should be considered. A reduction in the permeability of the dentin, achieved by sealing the dentinal tubules, is of paramount importance. Nd:YAG and 9.6-μm CO_2 lasers can be used for this purpose. The properties of these two lasers are described in an earlier section of this article. The 9.6-μm CO_2 laser energy is well absorbed by the hydroxyapatite of enamel and dentin, causing tissue ablation, melting, and resolidification [76]. The use of 9.6-μm CO_2 laser did not cause any noticeable damage to the pulpal tissue in dogs [77].

The effect of Nd:YAG laser energy on intrapulpal temperature was investigated by White et al [78]. They found that the use of a pulsed Nd:YAG laser with an energy level of below 1 W, a 10-Hz repetition rate, and an overall 10-second exposure time did not significantly elevate the intrapulpal temperature. According to their results, these parameters may be considered safety parameters because the remaining dentinal thickness in cavity preparations cannot be measured in vivo. It is therefore recommended that clinicians choose laser parameters lower than these safety limits.

Cleaning and shaping the root canal system

Periradicular periodontitis following pulp necrosis is caused by microorganisms and their products emanating from the root canal system [79–81]. Successful endodontic therapy, which mainly depends on the elimination of microorganisms from the root canal system, is accomplished by means of biomechanical instrumentation of the root canal. Studies have shown, however, that complete removal of microorganisms from the root canal system is virtually impossible [82,83] and a smear layer covering the instrumented walls of the root canal is formed [84–86]. The smear layer consists of a superficial layer on the surface of the root canal wall approximately 1 to 2 μm thick and a deeper layer packed into the dentinal tubules to a depth of up to 40 μm [86]. It contains inorganic and organic substances that also include microorganisms and necrotic debris [87]. In addition to the possibility that the smear layer itself may be infected, it also can protect the bacteria already present in the dentinal tubules by preventing the application of successful intracanal disinfection agents [88]. Pashley [89] considered that a smear layer containing bacteria or bacterial products might provide a reservoir of irritants. Thus, complete removal of the smear layer would be consistent with the elimination of irritants from the root canal system [90].

According to Oguntebi [91], the most currently used intracanal medicaments have a limited antibacterial spectrum and some of them have a limited ability to diffuse into the dentinal tubules. In his review, he suggested that newer treatment strategies designed to eliminate microorganisms from the root canal system must include agents that can penetrate the dentinal tubules and destroy the microorganisms because they are located in an area beyond the host defense mechanisms where they cannot be reached by systemically administered antibacterial agents. It also was clearly demonstrated that more than 35% of the canals' surface area remained unchanged following instrumentation of the root canal using four nickel-titanium preparation techniques [92].

In various laser systems used in dentistry, the emitted energy can be delivered into the root canal system by a thin optical fiber (Nd:YAG, erbium,chromium:yttrium-scandium-gallium-garnet [Er,Cr:YSGG], argon, and diode) or by a hollow tube (CO_2 and Er:YAG). Thus, the potential bactericidal effect of laser irradiation can be used effectively for additional cleansing of the root canal system following biomechanical instrumentation. This effect was studied extensively using lasers such as CO_2 [93,94], Nd:YAG [95–98], excimer [99,100], diode [101], and Er:YAG [102–104].

The apparent consensus is that laser irradiation emitted from laser systems used in dentistry has the potential to kill microorganisms. In most cases, the effect is directly related to the amount of irradiation and to its energy level. It also has been documented in numerous studies that CO_2 [105], Nd:YAG [105–107], argon [105,108], Er,Cr:YSGG [109], and Er:YAG [110,111] laser irradiation has the ability to remove debris and the smear layer from the root canal walls following biomechanical instrumentation.

There are several limitations that may be associated with the intracanal use of lasers that cannot be overlooked [112]. The emission of laser energy from the tip of the optical fiber or the laser guide is directed along the root canal and not necessary laterally to the root canal walls [113]. Thus, it is almost impossible to obtain uniform coverage of the canal surface using a laser [112,113]. Another limitation is the safety of such a procedure because thermal damage to the periapical tissues potentially is possible [56,112]. Direct emission of laser irradiation from the tip of the optical fiber in the vicinity of the apical foramen of a tooth may result in transmission of the irradiation beyond the foramen. This transmission of irradiation, in turn, may affect the supporting tissues of the tooth adversely and can be hazardous in teeth with close proximity to the mental foramen or to the mandibular nerve [113]. In their review, Matsumoto and colleagues [56] also emphasized the possible limitations of the use of lasers in the root canal system. They suggested that ‘‘removal of smear layer and debris by laser is possible, however it is difficult to clean all root canal walls, because the laser is emitted straight ahead, making it almost impossible to irradiate the lateral canal walls.’’ These investigators strongly recommended improving the endodontic tip to enable irradiation of all areas of the root canal walls.

Stabholz and colleagues [113,114] recently reported the development of a new endodontic tip that can be used with an Er:YAG laser system. The Er:YAG laser has gained increasing popularity among clinicians following its approval by the Food and Drug Administration for use on hard dental tissues [115]. The beam of the Er:YAG laser is delivered through a hollow tube, making it possible to develop an endodontic tip that allows lateral emission of the irradiation (side-firing), rather than direct emission through a single opening at its far end.

This new endodontic side-firing spiral tip (RCLase; Lumenis, Opus Dent, Israel) was designed to fit the shape and the volume of root canals prepared by nickel-titanium rotary instrumentation. It emits the Er:YAG laser irradiation laterally to the walls of the root canal through a spiral slit located all along the tip. The tip is sealed at its far end, preventing the transmission of irradiation to and through the apical foramen of the tooth (Figs. 3 and 4).

The dentinal tubules in the root run a relatively straight course between the pulp and the periphery, in contrast to the typical S-shaped contours of the tubules in the tooth crown [87]. Studies have shown that bacteria and their by-products, present in infected root canals, may invade the dentinal tubules. The presence of bacteria in the dentinal tubules of infected teeth at approximately half the distance between the root canal walls and the cementodentinal junction also was reported [116,117]. These findings justify the rationale and need for developing effective means of removing the smear layer from root canal walls following biomechanical instrumentation. This removal would allow disinfectants and laser irradiation to reach and destroy microorganisms in the dentinal tubules.

A recently completed pilot study [113] examined the efficacy of the endodontic side-firing spiral tip in removing debris and smear layer from distal and palatal root canals of freshly extracted human molars that were instrumented using nickel-titanium (ProTaper; Dentsply, Tulsa Dental, Tulsa Oklahoma) files to size F3. Following root canal preparation, the pulp chamber and the root canals of the prepared teeth were filled with 17% EDTA and irradiated with Er:YAG laser (Opus 20, Lumenis, Opus Dent, Israel), using 500 mJ per pulse at a frequency of 12 Hz for four cycles of 15 seconds each. The RCLase Side-Firing Spiral Tip was used for the irradiation. The lased roots were removed, split longitudinally, and submitted for SEM evaluation (Fig. 5).

Distal and palatal roots of freshly extracted human molars that had undergone similar preparation but were not lased served as control. SEM of the lased root canal walls revealed clean surfaces, free of smear layer and debris. Open dentinal tubules were clearly distinguishable (Fig. 6). In contrast, SEM of the nonlased root canals showed the presence of smear

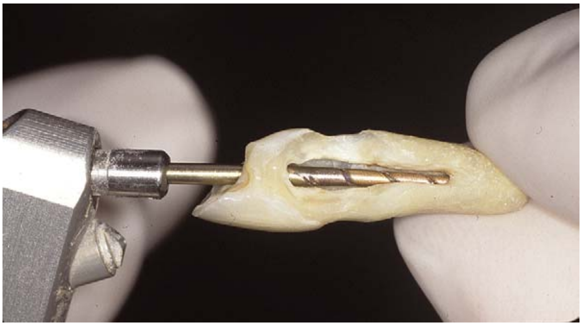

Fig. 3. The prototype of the RCLase Side-Firing Spiral Tip is shown in the root canal of an extracted maxillary canine in which the side wall of the root was removed to enable visualization of the tip.

Fig. 4. The RCLase Side-Firing Spiral Tip.

layer and debris all over the surfaces of the root canal walls, completely covering the openings of the dentinal tubules (Fig. 7). It appears that an efficient cleansing of the root canal system can be achieved by using the Er:YAG laser with the RCLase Side-firing Spiral Tip after biomechanical preparation of the root canal with nickel-titanium (ProTaper) files (Fig. 8).

Endodontic surgery

Surgical endodontic therapy is the treatment of choice when teeth have responded poorly to conventional treatment or when they cannot be treated appropriately by nonsurgical means. The goal of all endodontic surgery is to eliminate the disease and to prevent it from recurring [118]. The surgical option should be considered only when a better result cannot be achieved by nonsurgical treatment [119,120].

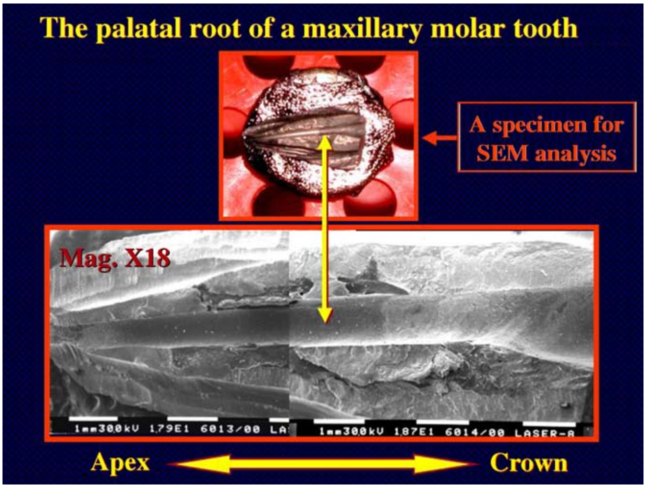

Fig. 5. Longitudinally split palatal root of a maxillary molar, sputter coated by gold and ready for SEM evaluation. The vertical arrow indicated the root canal as shown on the SEM photograph.

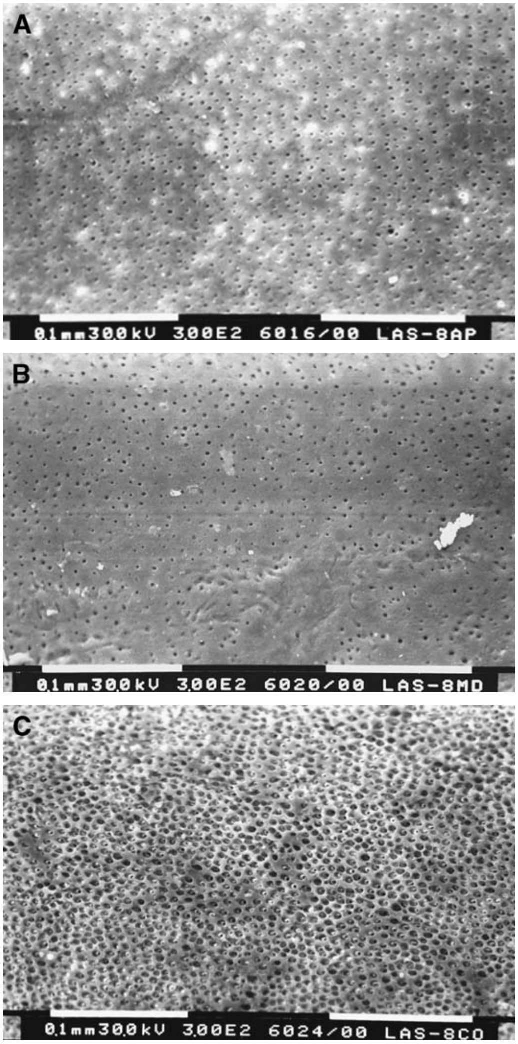

Fig. 6. SEM photographs of a lased wall of a root canal at its (*A*) apical, (*B*) middle, and (*C*) coronal parts demonstrate very clean surfaces of the root canal walls, free of smear layer and debris, and clean open dentinal tubules (magnification ×300).

Egress of irritants from the root canal system into the periapical tissues is considered the main cause of failure following apicoectomy and retrograde filling [121]. It is assumed that the irritants penetrate mainly through a gap present between the retrograde filling and the dentin. Consequently, many efforts have been made to improve the adaptation of retrofilling material to the dentin. The sealing efficacy of various retrograde filling materials such as amalgam, IRM, composite resins, glass ionomer cements, super EBA, and

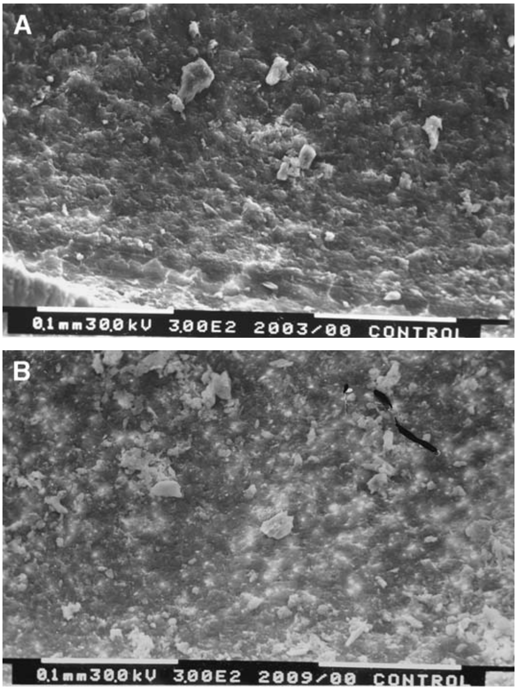

Fig. 7. SEM photographs of a nonlased wall of a root canal at its (*A*) apical and (*B*) middle parts demonstrate unclean surfaces of the root canal walls, with smear layer and debris. The dentinal tubules cannot be seen (magnification ×300).

mineral trioxide aggregate was evaluated to find the optimal material for this purpose [122–127].

A second possible pathway for irritants to invade the periapical tissues is through the dentin of the cut root surface after apicoectomy and retrograde filling. It was shown that the dentin of apically resected roots is more permeable to fluids than the dentin of nonresected roots [128]. There are large numbers of exposed dentinal tubules on the cut root surface; the coronal margin of an apical bevel, near the cementodentinal junction, has approximately 13,000 dentinal tubules per square millimeter [129].

The pattern of this leakage also was investigated and it was suggested that the angle on the bevel of the root surface should be kept to a minimum and the retrograde root fillings should extend to the most coronal aspect of the bevel. The importance of the sealing and the coverage of the apical foramen and that of the exposed dentin surfaces was emphasized [128–131]. Reducing or eliminating the permeability of resected apical dentin would seem advantageous in apical endodontic procedures [132]. Apical dye penetration was reduced by using dentin bonding material in the root-end preparation and covering the bevel [133]. The response of the periapical

Fig. 8. (*A*) Preoperative radiograph of a second left maxillary premolar with chronic apical periodontitis. A periapical radiolucent area can be seen clearly; a root canal re-treatment is indicated. (*B*) Following access opening, the old root canal filling material was removed; the occlusal view shows very unclean root canals. (*C*) A length-measurement radiograph demonstrates the presence of two separate root canals. (*D*) Using Er:YAG laser irradiation for cleaning of the root canal system. The RCLase Side-Firing Spiral Tip is introduced to the root canal after biomechanical preparation of the root canal with nickel-titanium (ProTaper) files was completed. (*E*) Radiograph of RCLase in canal. (*F*) Master-point radiograph of guttta percha in canal. (*G*) Radiograph showing both root canals filled with gutta-percha. (*H*) A 6-month postoperative radiograph shows good repair. (Courtesy of Dr. Ronit Maor, Jerusalem, Israel)

tissues to these materials and the longevity of their efficient seal in the periapical environment, however, still have to be determined [132].

Weichman and Johnson [134], who attempted to seal the apical foramen of freshly extracted teeth in which the pulp had been removed from the root canal, were the first to use lasers in endodontics. High-power (CO_2) laser energy was used to irradiate the apices of the teeth. Melting of the cementum

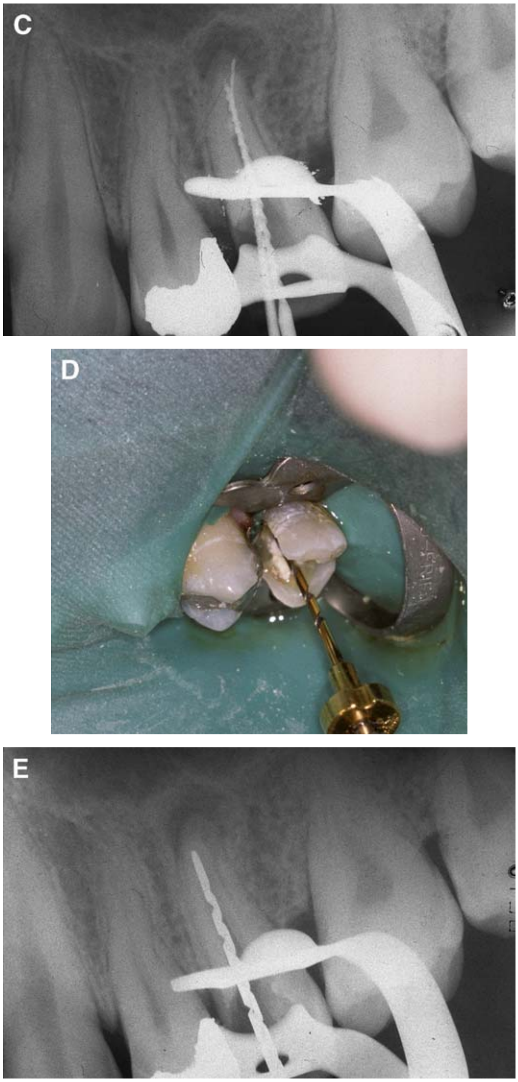

Fig. 8 (*continued*)

and dentin with eventual "cap" formation that could be dislodged easily proved that their goal was not achieved.

Miserendino [135] applied CO_2 laser energy to the apices of freshly extracted human teeth and demonstrated recrystallization of apical root dentin. The recrystallized structure was smooth and suitable for placement of retrograde filling material. He suggested that the rationale for laser use in endodontic periapical surgery should include the following: improved hemostasis and concurrent visualization of the operative field, potential

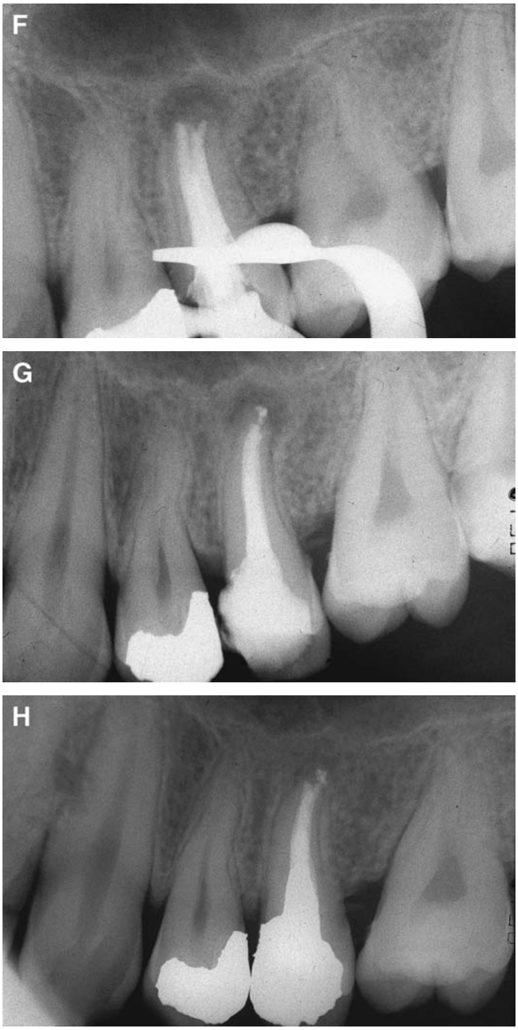

Fig. 8 (*continued*)

sterilization of the contaminated root apex, potential reduction of the permeability of the root surface dentin, a reduction in postoperative pain, and a reduced risk of surgical site contamination by eliminating the use of aerosol-producing air turbine handpieces for apicoectomy. Despite its potential to lower dentin permeability, the conclusions of an in vivo study were that the use of CO_2 laser in apical surgery on dogs did not improve the success rate following surgery [136]. A prospective study of two retrograde endodontic apical preparations with and without CO_2 laser, in which 320 cases were evaluated, did not show that CO_2 laser improved the healing process [137].

In vitro studies [41,42,138,139] using the Nd:YAG laser have shown a reduction in the penetration of dye or bacteria through resected roots. It was suggested that the reduced permeability in the lased specimens probably was the result of structural changes in the dentin following laser application [42]. Although SEM examination showed melting, solidification, and recrystallization of the hard tissue, the structural changes were not uniform and the melted areas appeared connected by areas that looked like those in the nonlased specimens. It was postulated that this was the reason why the permeability of the dentin was reduced but not completely prevented. It is reasonable to assume that homogeneously glazed surfaces would be less permeable than partially glazed ones. Ebihara et al [140] used Er:YAG laser for retrograde cavity preparations of extracted teeth. They found no significant difference in dye penetration between the laser-treated groups and those in which ultrasonic tools were applied. As mentioned earlier, the Er:YAG laser does not melt or seal the dentinal tubules; therefore, these investigators did not observe any reduction in dentin permeability.

The authors believe that after the appropriate wavelength for melting the hard tissues of the tooth has been established, the main contribution of laser technology to surgical endodontics (apicoectomy and so forth) is to convert the apical dentin and cementum structure into a uniformly glazed area that does not allow egress of microorganisms through dentinal tubules and other openings in the apex of the tooth. Hemostasis and sterilization of the contaminated root apex also have a significant input.

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