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Erbium lasers in dentistry

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The first lasers were developed in 1964 and, almost immediately, the desire to use this new technology in medical applications began. The evolution and growth of the use of lasers in medicine during the last 2 decades occurred initially within the disciplines of ophthalmology, dermatology, and general surgery [1–9]. The general acceptance today of the role of soft tissue surgical lasers in many medical specialties by patients and by physicians allows surgeons to operate in a partially or completely bloodless field as a suitable alternative to traditional surgical treatment regimens.

This acceptance of lasers as viable alternatives to traditional methods in medicine was one of the events that created an explosion of interest in the last decade in the role of lasers in dentistry. Once thought of as a technology looking for a purpose in dentistry, soft tissue lasers, over the last decade, have evolved from a possible choice to an accepted, presently used methodology. Even though soft tissue lasers have found a niche in medicine and in dentistry, the real hope for many patients and dentists has been the development of a laser that would be able to remove hard tissue in a conservative and safe manner.

Hard tissue lasers, first developed in the 1990s, came to the dental marketplace in 1997. These hard tissue erbium lasers have the capability to prepare enamel, dentin, caries, cementum, and bone in addition to cutting soft tissue. The ability of hard tissue lasers to reduce or eliminate vibrations, the audible whine of drills, microfractures, and some of the discomfort that many patients fear and commonly associate with high-speed handpieces is

Since 1999, the author has used the Hoya Con Bio DeLight (2940-nm wavelength) erbium:yttrium-aluminum-garnet laser routinely in his practice. The author receives honorariums from various laser companies including Hoya Con Bio for lectures he provides. The author owns no stock in any laser company and has no other financial interest in any other particular laser company.

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impressive. In addition, these lasers can be used with a reduced amount of local anesthetic for many procedures, which is another feature that makes the hard tissue laser very exciting for needle-phobic patients.

Today, these instruments have evolved from their initial use for all classes of cavity preparations to their ability for removing soft tissue, their usefulness in the disinfection of bacteria within endodontic canals, and most recently, as an alternative to the high-speed handpiece for the removal of bone in oral and maxillofacial surgery. In addition, recent research has centered on the value of the erbium family of laser wavelengths in periodontics, including the removal of calculus.

Historical review

Since the introduction of the first ruby laser by Goldman et al [10] and Stern and Sognnaes [11], many wavelengths have been investigated, first for their clinical applications in medicine and then, in turn, for dentistry.

The appearance of the pulsed Nd:YAG laser, developed by Myers and Myers and cleared by the US Food and Drug Administration (FDA) in 1989 for intraoral soft tissue surgery, began the development of lasers specifically manufactured and cleared for dentistry. Many of the early wavelengths developed for dentistry were designed for applications on soft tissue only. These lasers had little tissue interaction with hard tissue.

Over the years, numerous wavelengths have been investigated for their effectiveness in preparing dental hard tissues. Vahl [12], when using a ruby laser, found that there was crater formation and melting of dentin when treating deep carious areas. Kantola [13] found similar destruction to enamel and dentin with a carbon dioxide (CO_2) laser. Other studies also have discovered that energy from a variety of lasers including CO_2, Nd:YAG, and others left puddled craters in enamel and dentin, with melting and recrystallization of these hard tissues [14–18]. Wigdor et al [19] reported that there was a loss of the odontoblastic cellular matrix with the use of the CO_2 laser. Lenz et al [20] found that when using the Nd:YAG laser on incipient early carieslike lesions, tooth enamel surfaces were sealed and the lesions were inhibited. They also discovered that pulpal temperatures could become elevated to the point of pulpal damage if proper energy settings were not followed [20]. Harris et al [21] discovered that because the Nd:YAG laser is absorbed by carious rather than healthy enamel, surface carious enamel lesions could be removed without histologic or clinical signs of pulpal vitality being altered. Due to the Nd:YAG laser having an affinity for pigmented tissue, topical pigmented initiator was required to ablate sound dentin. Frentzen and Koort [22] concluded that using the Nd:YAG laser produced zones of debris and carbonization, along with areas of necrosis and microcracks. It became apparent in many studies [23–26] that unless structural damage to enamel and dentin caused by heat along with the unwelcome rise in pulpal temperatures could be reduced, the laser would not become a replacement for the high-speed handpiece in the preparation of teeth.

Although high-powered photothermal lasers effectively can be used to cut and coagulate soft tissue, their use in hard tissue procedures was not possible until further advances in laser technology occurred in the late 1980s. These soft tissue lasers had too low a thermal ablation efficiency or the thermal effects were too high, or both. In 1988, Paghdiwala [27] tested the erbium:yttrium-aluminum-garnet (Er:YAG) wavelength for its ability to ablate dental hard tissues. For the first time, a laser was used to create preparation holes in enamel and dentin with low energies. Without any water cooling, the prepared holes showed none of the typical heat-induced microcracks and little or no charring. The pulpal cavity temperature increase was shown to have a mean rise of 4.3°C, well within the margin of pulpal safety.

Studies between 1998 and 1991 by Hibst and colleagues [28,29] and Keller et al [30] showed that tooth structure could be removed by the Er:YAG wavelength without causing any measurable degree of thermal damage. Furthermore, these studies showed that thermal damage to enamel and dentin was minimal when proper settings were used and an adequate water cooling spray was employed. The procedure was comfortable (relatively little pain was felt by the patient) and deemed to be safe and efficacious. Although preparation time for the laser procedure was approximately twice that of a high-speed handpiece, pulp vitality was maintained. Ablation of tooth structure was about one order of magnitude lower than for soft tissue and about two to four times lower than for bone [31].

During the mid-1990s, research examined the safety and value of using the Er:YAG wavelength for preparation of hard tissues [32–36]. In these studies, it was seen that this wavelength (when used with water) would ablate solid tooth structure without thermal damage. If the wavelength was used without a water spray, then typical microcracks and other thermal damage seen with previous lasers would appear.

Although the first Er:YAG laser system (Kavo Key Laser, Kaltenbach and Voigt GmbH & Co., Biberach/Riss, Germany) was introduced into the medical market in Germany in 1992, it was not until 1997 that erbium dental lasers received FDA clearance in the United States. With this clearance came approval for caries removal, cavity preparation, and conditioning of the tooth [37]. The Er:YAG laser was able to provide precise ablation of sound and carious enamel and dentin with a shallow thermal penetration depth.

In the last 6 years, two wavelengths have been developed for use clinically on hard tissues. These include the Er:YAG (2.94 μm) and the erbium,chromium:yttrium-scandium-gallium-garnet (Er,Cr:YSGG) at 2.78 μm, which by many scientific accounts have very similar properties. These two wavelengths make up the erbium family of lasers. Preliminary studies looking at the safety and efficacy of using the Er,Cr:YSGG wavelength found it to be a precise tool for bone and dental hard tissues [38–41].

It is these two wavelengths (Er:YAG and Er,Cr:YSGG) that dominate the hard tissue laser market as it stands in 2004. It should be noted that every attempt was made to research all published articles in the preparation of this article. Manufacturers of various hard tissue lasers were forthcoming with their research with the exception of Biolase (BIOLASE Technology, San Clemente, California). Despite numerous attempts to obtain purported research showing the uniqueness of this wavelength with respect to mechanism of action and distinctive usages on dental tissues, no research abstracts were made available to the author. The reference section and the article in general, therefore, can include only peer-reviewed published material as it stands as of this time. Every effort has been made to provide a balanced and neutral viewpoint on the role of all erbium lasers in dentistry today from the published research available to the public at large.

Hard tissue laser biophysics

In considering the biologic effects of laser light on dental tissue—specifically, hard tissue—there are many factors to consider. These factors include the specific wavelength of the laser, the energy density, the pulse duration of the laser radiation, and the properties of the tissue interacting with the light. These properties include absorption, transmission, scattering, and reflection of the laser energy.

All erbium lasers share a common characteristic of an affinity for the wavelengths to be highly absorbed by water, hydroxyapatite, and collagen. The highest peaks for the absorption of laser energy in water are at 3 μm and 10 μm. The Erbium:YAG wavelength at 2.94 μm exactly matches the absorption peak of water; moreover, the absorption coefficient in water for the 2.94 μm Er:YAG wavelength is significantly higher than of the 2.78 μm Er,Cr:YSGG (Table 1) [42].

The optical penetration depth of the erbium lasers (Er:YAG and Er,Cr:YSGG) are only a few micrometers. For the Er:YAG laser, the actual depth of penetration is around 5 μm when using a 300-microsecond

Table 1
Absorption coefficients of several wavelengths in water and enamel

Laser wavelength	Absorption coefficient in water (absorption depth[a])	Absorption coefficient in enamel (absorption depth[a])
2.1 μm (holmium:yttrium-aluminum-garnet)	25 cm^{-1} (400 μm)	<5 cm^{-1}
2.78 μm (Er,Cr:YSGG)	6500 cm^{-1} (1.6 μm)	400 cm^{-1} (25 μm)
2.94 μm (Er:YAG)	12,250 cm^{-1} (0.9 μm)	800 cm^{-1} (13 μm)
9.6 μm (CO_2)	590 cm^{-1} (17 μm)	8000 cm^{-1} (1.3 μm)

[a] Depth at which intensity falls to (1/e) of initial intensity.

Data from Walsh LJ. The current status of laser application in dentistry. Austral Dent J 2003;48:149.

pulse width [29]. When the laser energy is focused onto the tooth, the superficial layer of tooth structure, along with the water contained therein, is heated rapidly. The water is vaporized almost instantaneously, and the steam causes an increase in the irradiated volume. This expansion surpasses the crystal strength of the dental structures, and the material breaks. This explosive ejection of the ablated debris starts very shortly after the onset of the laser irradiation and lasts until the power drops. The speed of the ablation is such that very little heat is transferred to the surrounding tissue. The heating of the tooth that does occur comes from the remaining tissue volume at the crater bottom and from tooth structure irradiated at an energy level just below the ablation threshold. When the laser energy is increased, it lowers the ablation threshold and, in turn, accelerates the ablation process, thus lowering the thermal side effects. Another consideration is that when the energy is increased, the pressure and velocity of the ejected material increases, which results in a more intense impact on the target site. This increased impact creates larger mechanical side effects and, with higher irradiance, plasma also is ignited, which considerably reduces the efficiency. A very compelling manner of decreasing the heat without increasing energy is to cover the operating site with a thin film of water [37].

Fried et al [43] demonstrated that when an applied layer of water of sufficient thickness is applied, it has a profound effect on ablation rate, ablation efficiency, and the surface morphology of the crater walls. Rechmann et al [44] also showed that when troughs were cut in dental enamel without a water spray, a loosely attached layer of fused enamel remained. It is thought that this layer of enamel would be deficient in water and more resistant to further ablation from Er:YAG laser pulses.

The manner in which the mechanism of ablation occurs is not clearly understood and has been somewhat controversial. Early studies focused on tissue dehydration; however, water-absorption studies showed that only approximately one half the water is diffusible and that the rate of water diffusion is so slow that it is in the manner of several hours to days [35,45–48]. Thermal analysis studies have shown that the target tissue needs to be heated to a minimum temperature of 200°C to 300°C before the diffusible water is removed [48]. Temperatures of up to 800°C are required to remove water that is more tightly bound in the tooth structure [49]. For this reason, it is not likely that dehydration by diffusion of water is largely responsible for the effect of laser ablation of dental tissue.

Other purported hypotheses for the mechanism of ablation include cavitation bubbles, apatite crystalline fragments, and for one wavelength (Er,Cr:YSGG), the manufacturer suggested that the laser light accelerates water droplets. This proposed mechanism of action was dubbed ''hydrokinetics,'' meaning that water droplets are accelerated rapidly into the enamel by absorption in the laser beam [38,39].

No published research available today can verify whether there is any uniqueness of a mechanism of action for any particular wavelength within the erbium family of lasers. The thermomechanical ablation process described is true for Er:YAG and Er:YSGG instruments. High-speed photography and the scientific literature published up to now cannot give any credence to "hydrokinetic effect" as being a viable means of how laser ablation occurs [37,43,50]. Freiberg and Cozean [50] also concluded from their 2002 study that "if the proposed hydrokinetic effect exists, it is not effective on hard materials, which are void of water, and it does not contribute in any significant degree in the ablation of dental enamel."

It is now accepted that the mechanism of action for laser ablation in enamel is basically the same for all lasers that fall within the erbium family: the rapid subsurface expansion of the interstitially trapped water within the mineral substrate causes a massive volume expansion, and this expansion causes the surrounding material to be exploded away. Due to the water spray and the short pulse duration, there is a minimal amount of heat transferred to the remaining and adjacent tooth structure [50]. A feature of all erbium lasers is a popping sound when the laser is interacting with dental tissues. This popping sound, in fact, is a very quick shock wave that is created when the laser energy dissipates explosively. This popping sound is called the photoacoustic effect. The pitch and resonance of this sound wave varies according to the presence or absence of decay in the tooth [42,51]. This photoacoustic effect is characteristic of a short pulse duration (100–250 microseconds) and a high energy density [52].

In addition to the photoacoustic effect, the erbium laser has, in a fashion similar to other wavelengths, a bactericidal effect [53–55]. The erbium wavelength is absorbed by water in the bacterial cells, and the cells undergo the same liquid-to-steam vaporization that is seen during ablation of hard tissue [56]. This destruction of bacteria is one of the additional advantages of using lasers for soft or hard tissue dental procedures.

The issue of hard tissue laser biophysics has been and remains a controversial area. This controversy is apparent especially with respect to whether the mechanism of action is identical within the different erbium laser wavelengths (Er:YAG and Er,Cr:YSGG). At present, there is no published research that substantiates claims to a unique mechanism of action for any specific wavelength. Further research is necessary to substantiate the theory that unique mechanisms of action are at play during ablation of dental hard tissues.

Technical considerations for erbium laser delivery systems

The Er:YAG and Er,Cr:YSGG wavelengths cannot be delivered through quartz optical fibers like soft tissue lasers (eg, diode and Nd:YAG) can. "Infrared fibers" that are made of materials other than quartz transmit the midinfrared wavelengths needed to deliver the laser energy to the surgical site. Quartz fiber transmission of wavelengths between 300 and 2400 nm is efficient, but outside of this range, there is a dramatic reduction in transmission of the energy. The quality of these fibers continues to grow from when the first lasers were introduced to dentistry in 1997. Miserendino, in an independent study published by Manni [57] on the first Er:YAG laser cleared for dentistry, stated that only 11% of users obtained more than 100 uses out of their fiber, and 30% got 50 or more uses. Fibers now can last for years and for hundreds to thousands of procedures. Proper care of the optical fiber while cleaning the handpiece and tips is essential to prolonging the lifetime of the fiber. There are at present three different methods of carrying the laser energy from the unit to the handpiece. The first method is through a special optical fiber of zirconium aluminum fluoride or a similar substance with negligible water content. The second alternative is a flexible hollow wave guide—a specially designed hollow tube that guides the laser energy through reflection on the internal walls of the tube. Hollow wave guides are less expensive than optical fibers but have a relative lack of flexibility and are shorter overall in length (from 12 in to 4 ft or so). The third method of carrying the laser energy is through an articulated arm, which traditionally was used for long wavelengths such as CO_2.

At the distal end of the fiber is a handpiece. These handpieces often are designed to have removable tips that can be sterilized and reused. Many dentists can get 30 to 50 uses out of a tip before it becomes so chipped and worn that it requires replacement. These tips can be in or out of contact with the tooth structure, depending on the manufacturer. Two basic handpiece options exist. The first looks similar to a high-speed handpiece in which the replaceable tips are inserted and removed in a similar fashion to burs. The other handpiece design appears to look like a pen and has replaceable tips that have a gentle curve to them. The handpiece design depends on the manufacturer of the unit.

Role of hard tissue lasers in restorative dentistry

In 1997, the FDA cleared the Er:YAG laser for caries removal, cavity preparation, and laser etching of enamel. The clearance of the first Er:YAG (2.94 μm) laser focused on the ability of this wavelength to create class I, II III, IV, and V dental preparations, and its role in restorative dentistry was established. Extensive studies (FDA human clinical trials) were completed that included clinical, histologic, radiographic, and dye penetration studies of 1700 teeth [58].

The FDA studies demonstrated the following features [52]:

- Pulpal vitality is not compromised.
- Tooth structure is equivalent between laser and control groups and surface morphology does not change except at treatment site.
- There is efficacy of standard dental treatment and various laser wavelengths for etching and cavity preparation (animal studies).

The laser can remove caries completely and effectively.
The laser can perform cavity preparation effectively.
The laser can etch teeth effectively.
The quality of the cavity preparation (before restoration) is equivalent to that obtained with a dental handpiece: scanning electron microscopic and visual assessment show sharpness of walls; dye penetration studies show bonding between composites and tooth structure; shear strength testing on extracted teeth shows strength of composite restorations.

A large number of studies exist in the literature that elaborate on each of the above areas. Some studies were released before and some were released after the Er:YAG laser received FDA clearance. More research articles continue to be released, and they demonstrate the relative safety of the erbium lasers for caries removal, cavity preparation, and enamel modification. Specific discussion on the role of lasers in restorative dentistry in these areas is discussed in the following sections.

As mentioned earlier, a water spray is necessary with all erbium lasers to act as a heat sink and to prevent thermal damage to adjacent tissue. Numerous studies have shown that pulpal temperature is not increased to a level that can cause an irreversible pulpitis in teeth treated with erbium lasers. Glockner et al [59] demonstrated that there was a change after a few seconds of using the Er:YAG laser that decreased the pulpal temperature from 37°C to between 25°C and 30°C. This drop in pulpal temperature occurred as result of the water and air spray that accompanied the laser. In vitro studies found an increase in pulpal temperature only when the embedded probe in the root canal was accidentally and directly hit with the laser beam. Interestingly, the study found that when a bur was used, the temperature in the pulp could rise up to 60°C even before the pulp chamber was exposed with the bur. Oelgiesser et al [60] looked at class I to V preparations in 175 freshly extracted teeth and examined the pulpal temperature increases. They discovered that the highest temperature rises were 3°C to 4°C in class I preparations, medium increases of 2°C to 4°C were seen in class V preparations, and the lowest increases were 2°C to 3°C in cementum preparations. Caries removal resulted in temperature increases of 1°C to 3°C. All preparations were below the critical pulpal increase for the maintenance of pulpal vitality, which is 5.5°C. Takamori [61] showed that after preparation with the Er:YAG laser, the traditional increase and corresponding return to normal in the calcitonin gene-related peptide-immunoreactin fibers in the pulp occurred earlier than in the control group of high-speed drill preparations. These results were taken by the group to show that the Er:YAG laser leads to initiation and completion of pulpal repair earlier than with the high-speed drill. Rizoiu et al [62] found similar pulpal responses for the Er,Cr:YSGG laser system. Jayawardena et al [63] looked at the pulpal response to accidental exposure of dental pulps in rats when using the Er:YAG laser. No bleeding and no dentin chips were observed immediately after the exposure and, subsequently, dentin bridges at the exposure site were more commonly visible than in the control group. The Er:YAG group also had more reparative dentin near the exposure site than the control group of slow-speed handpiece pulpal exposures.

Preparations with the erbium lasers seen from histology slides show no immediate, short-term, or long-term negative effects compared with the conventional dental drill [64]. There was moderate hyperemia in the immediate area of the cut dentinal tubules when the preparations were within 1 to 1.5 mm of the pulp. There remained an orderly organization of both the odontoblastic and subodontoblastic layers, and histologically, the preparations were similar to those cut with traditional high-speed handpieces. Hyperemia that resulted was transient and localized to the pulp adjacent to the cavity preparation and should be considered as a normal physiologic response. Pulpal response to cavity preparations with the Er,Cr:YSGG wavelength in enamel and dentin also have been shown to produce no visible inflammatory response 30 days after the preparations were completed [65]. Other studies have shown that the Er,Cr:YSGG wavelength can be used on root surfaces and at high energy settings without causing untoward morphologic changes such as melting or carbonization [66–68].

The preparations produced by the Er:YAG and Er,Cr:YSGG lasers have a characteristically chalky surface when used on enamel. Scanning electron microscopic images show that laser irradiation produces a surface that increases the restorative material retention. The surface is ideal for the use of composite and compomer filling materials [37,69]. Many studies have examined the ability of the erbium lasers to improve bond strength and marginal seal. Most of the studies have been completed in the last few years, and the methods and results from these research articles vary tremendously [69–82].

As early as 1996, Visuri [72] showed that laser-irradiated samples had improved bond strengths compared with acid-etched and handpiece controls and concluded that the Er:YAG laser preparation of dentin leaves a suitable surface for strong bonding of an applied composite material. Lin et al [75] showed that bond strengths for nonetched enamel were much higher in the Er,Cr:YSGG laser-cut surfaces compared with bur-cut surfaces, but no differences occurred between the two groups when looking at bond strengths on dentin. Ramos et al [79] found that all lased subgroups had a decrease in bond strength compared with control groups, and this drop was most evident for single-bottle bonding agents. The best of the lased group was found in those teeth in which bonding to dentin was accomplished with a self-etching primer system. When bonding to enamel for orthodontic brackets, the results again are mixed, with Lee et al [80] discovering positive results for laser etching before bonding brackets and Martinez-Insua et al [78] discovering the opposite results.

In looking at the Er,Cr:YSGG wavelength, Usumez and colleagues [81,82] released two recent studies that evaluated the bonding of orthodontic brackets in one study and the bonding of porcelain veneers to lased enamel surfaces in the other. They claimed that enamel conditioning with an Er,Cr:YSGG laser at 2 W of power (20 Hz, 100 mJ) can be seen to be equivalent in bond strength to acid etching. Cutting the power in half (20 Hz, 50 mJ) significantly decreased the bond strength of the irradiated surface compared with acid etching, but there were large variations in individual results, so they advised that the Er,Cr:YSGG laser alone cannot be considered a successful alternative to conventional methods of increasing bond strengths to enamel. In their most recent study, Usumez and Aykent [83] found that bond strengths of porcelain laminate veneers bonded to tooth surfaces that were laser etched showed results similar to orthophosphoric acid or maleic acid–etched tooth surfaces. Yu et al [83] also confirmed that the Er,Cr:YSGG laser can contribute to an enhanced bond strength between restorative materials and dental hard tissues.

Fried et al [76] showed that if an optically thick layer of around 1 mm was applied continually to the surface of the dental enamel before each incident Er:YAG laser pulse, then it profoundly influenced the rate and efficiency of ablation and the resulting morphology of the ablated surface. These investigators went on to claim that composite restorative materials could be bonded to laser-prepared enamel without the necessity of further surface preparation or acid etching. The thick water layer prevented the formation of the undesirable calcium phosphate substrates that negatively effect bond strength.

In looking at these mixed and varied results of bond strength studies, several issues are worth noting. The variety in results may be due to the parameters of the laser, the material used for filling the preparations, and the combination of the laser-etched surface with or without acid etching. In using the erbium lasers for conditioning of enamel for optimum bonding, it is best to use the lowest possible energy level just below the ablation threshold. This technique helps to reduce the amount of ablation debris or tiny flakes that remain in the preparation. These ablation flakes can be poor surfaces to bond to and are best reduced in amount before bonding [37].

When considering bonding to irradiated dentin surfaces, the odontoblastic tubules are opened up during erbium laser procedures. Many clinicians now choose to use bonding agents that have a light self-etching primer or a one-bottle bonding system. It should be remembered, however, that at least one recent study [84] showed that when using an etch and rinse adhesive, separate acid etching of Er:YAG-irradiated enamel and dentin surfaces remains mandatory.

Studies have been published that evaluate how the erbium lasers can affect microleakage around class I and class V restorations. For class I restorations, studies have [85] shown that there is no difference in microleakage between enamel prepared with the laser and that prepared with the bur, so long as chemical etching of the enamel occurred first. The restorative material of choice from a microleakage study [70] was composite resin or glass ionomer because amalgam restorations showed moderate-to-severe leakage. Microleakage studies also have examined the effect of Er:YAG laser on class V preparations [86–90]. The studies show that all restorations prepared and restored at the cervical level have some form of microleakage, regardless of whether they are prepared with lasers or conventional methods. Er:YAG lasers do not eliminate microleakage, but the conclusions from the studies vary as to whether the microleakage is equivalent to those prepared with alternative methods such as air abrasion or the handpiece [88–90], or whether the Er:YAG may actually increase the level of microleakage that occurs on the restoration [86,87]. It cannot be assumed that the use of an erbium laser can be helpful to reduce the incidence of secondary caries. Apel et al [91], in their in vitro study, showed that enamel cavity preparations with the Er:YAG and Er,Cr:YSGG lasers for cavity preparations showed no advantages compared with conventional preparations in terms of resistance to secondary caries.

The clinical implications of these studies suggest that using an erbium laser should not be considered a method to enhance the ability of a restoration to resist microleakage. Composite and glass ionomer restorations are superior to amalgams when placed in preparations created by lasers.

The speed of preparing teeth with erbium lasers is somewhat slower than the high-speed handpieces. Shigetami et al [92] found that the time taken to remove carious enamel by laser irradiation was slightly longer compared with a control group (rotary cutting device). There was no difference between the laser and handpiece when the preparations were in dentin. This study did not take into account the overall speed of the entire procedures from the time the patient was seated until the patient was dismissed because in most cases, erbium preparations are made without local anesthetic. The time needed for the local anesthetic to take effect was not factored into this study, so that overall times may be comparable.

There always has been an interest in how the cutting speeds of various erbium lasers compare. Stock et al [93] performed a direct comparison of the cutting speeds of the Er:YAG and Er:YSGG lasers. Using the lasers at the same parameters and the same irradiation spot size and using identical optical fibers showed the same results in enamel ablation. Slight advantages were found for the Er:YAG laser in dentin ablation. The crater diameter and subsequent mass removal was greater using the Er:YAG laser, whereas the temperature increase during the ablation process was lower for the Er:YAG wavelength.. These investigators concluded that "both effects could be easily understood by a lower ablation threshold for the Er:YAG laser resulting from the higher absorption in dentin as mentioned."

The preparation of teeth by way of traditional methods using high-speed and low-speed handpieces is widely associated with discomfort to patients due to pain, noise, and vibrations. Erbium lasers have demonstrated for over 10 years the ability to make preparation in enamel and dentin with greatly reduced local anesthetic or no anesthetic at all [94–101].

Keller et al [94] and Matsumoto et al [95] looked at the Er:YAG and Er,Cr:YSGG wavelengths, respectively, with regard to the evaluation of patient perception and acceptance of using lasers for treatment. Keller et al [94] looked at 206 preparations distributed among 194 teeth. The laser treatment was found to be more comfortable than the mechanical treatment, with a high statistical significance. The need for local anesthetic was found to be necessary in 11% of mechanical preparations and 6% of laser-prepared teeth. Eighty percent of the patients found mechanical preparation to be more uncomfortable than laser preparations, and 82% of the patients wanted to have the laser for any future preparations involving caries removal. Keller et al [94] concluded that the Er:YAG laser system is a more comfortable alternative or adjunctive method to conventional mechanical cavity preparation.

Hadley et al [101] looked at the Er,Cr:YSGG laser and found it to be an effective laser for the preparation and restoration of class I, III, and V cavities for resin restorations.

Role of hard tissue lasers in soft tissue ablation

Erbium lasers, by their sheer nature of being well absorbed by hydroxyapatite, originally were considered primarily hard tissue lasers. It must remembered that the primary chromophore of the erbium family of lasers is water in the target tissue, and the largest component of soft tissue is water. Laser physics and absorption curves of various tissues have shown that the erbium family of lasers ablate soft tissue by the same mechanism as hard tissue. The laser energy from the infrared beam is converted into local thermal energy, and this energy creates a massive expansion in the target chromophore of water. The resulting microexplosions result in thin layers of tissue ablation. The erbium laser soft tissue removal process results in a "shaving" or "planing" of the tissue that clinically appears different than the deeper penetrating ablation process seen with dedicated soft tissue lasers [56]. Venugopalan et al [102] postulated that during the cutting of human mucosa, the Er:YAG targets the water molecules rather than the collagen matrix. The energy causes the water molecules to be heated into steam, which in turn strains and fractures the collagen matrix in the extracellular environment.

The depth of penetration of an Er:YAG laser using a 200- to 400-microsecond pulse width is in the range of 5 to 40 μm. There is as little as 5 μm of residual thermal damage [103]. This penetration depth is vastly different than the soft tissue lasers (diodes, Nd:YAG), whereby tissue effects can be as deep as 500 μm or more [104]. The collateral damage produced by the Er:YAG laser is minimal because the energy is absorbed in water and thermal damage is small (no charring), which may result in improved healing of the area. Neev et al [105] discovered that there is less collagen remodeling and, in turn, faster healing with minimal scar tissue presenting after erbium laser soft tissue surgeries.

Diode lasers (810–980 nm), unlike the erbium family, are very well absorbed in melanin and hemoglobin. These wavelengths will pass through water and penetrate much deeper into the soft tissue. Moreover, these wavelengths achieve hemostasis much better than the erbium lasers, which are not well absorbed by these chromophores. The erbium family, therefore, is not the ideal wavelength for soft tissue surgeries in which ideal hemostasis is desired. The degree of difficulty with hemostasis seems to be greatest in cases where the soft tissue initially is inflamed. Although the erbium laser can be used for gingivectomies, gingivoplasties, frenectomies, vestibuloplasties, excisional procedures, crown lengthenings, incisions and drainages, implant exposures during second-stage surgery, apthous ulcer palliative treatments, and the removal of melanin pigmentation, the clinician must show care to assure that no iatrogenic damage occurs in adjacent tissues such as bone, cementum, or dentin due to using the erbium laser for soft tissue procedures [106].

Erbium laser for bacterial reduction during endodontic therapy

There is much published research that shows that the erbium laser, like other lasers, has a bactericidal effect and, thus, can be used to help reduce the bacterial count in general. In addition, erbium lasers can be used specifically to reduce bacteria in the root canal during endodontic therapy [107–114]. These studies have shown that all lasers including the erbium family of lasers are effective in significantly reducing bacteria in the canals. In some instances, the bacteria removed by lasers are not affected by bleach (ie, *Enterococcus faecalis*). The use of erbium lasers in endodontics is discussed in more detail elsewhere in this issue.

Role of erbium lasers in periodontal disease

Because the popularity of the erbium family of lasers has increased in the last 5 years, many researchers have examined erbium lasers in the treatment of periodontal disease [107,115–119]. The published literature has shown that erbium lasers can be an alternative therapy for root surface debridement because the laser can ablate calculus without producing major thermal side effects to adjacent tissue. Other studies have shown that nonsurgical periodontal therapy with the Er:YAG laser leads to significant gain of clinical attachment [120,121]. These same studies looked at the instrumentation of pockets with the Er:YAG laser and found that there was minimal removal of tooth substance and no increase in gingival recession. The previously mentioned bactericidal effects of this wavelength have been noted in endodontic and periodontal therapy and have shown that this wavelength can be effective against periodontophathic bacteria [108]. Although these studies have shown promise for the use of lasers for periodontal treatment, there are several concerns that must be appreciated by those clinicians hoping to use this wavelength successfully for the treatment of nonsurgical periodontal therapy.

The Er:YAG laser will ablate not only calculus but also the underlying dentin, cementum, bone, and tissue. This wavelength is not selective for calculus. Numerous studies have shown that the erbium family of lasers will ablate the underlying cementum's superficial surface [115–117,122]. During the debridement of a diseased root surface, a certain amount of cementum ablation is acceptable whether an erbium laser or ultrasonic scaler is used. The issue is whether there is a significant increase in the amount of cementum removed when the erbium laser is used compared with the hand instruments or ultrasonic scalers traditionally used by the profession. Another concern is that alternative wavelengths such as Nd:YAG and diode are readily absorbed by pigmented periodontal bacterial and are able to significantly alter the flora within the pocket. The erbium family of wavelengths is not readily absorbed by these bacteria. In addition, the near-infrared wavelengths are much more selective for the removal of soft tissue and, therefore, able to ablate the chronically inflamed soft tissue on the inner wall of the periodontal pocket with very minimal damage to adjacent tissues (bone, cementum, dentin). For this reason, the use of Nd:YAG and diode wavelengths may be preferred over the erbium wavelengths until further research deems that the benefits outweigh the consequences.

Another investigated periodontal use of the erbium family of lasers is around implants and for the treatment of peri-implantitis. Walsh [123] and Schlenk et al [124] examined the role of erbium lasers in implantology in the early 1990s. El-Montaser et al [125] examined osseointegration in holes prepared with erbium lasers. They compared the erbium laser to burs in rat calvaria and found that osseointegration of titanium screws can be achieved using an Er:YAG laser to prepare the implant bed. Researchers recently have focused their attention on examining the role of erbium lasers in irradiating the surface of the implant and the possible role of these wavelengths in the decontamination of implant surfaces in peri-implantitis cases [109,126–130]. Kreisler et al [126] discovered that low settings of both Er:YAG and CO_2 lasers could be used around implants without damage to the implants; however, diode instruments were preferred for this procedure in their study. Kreisler et al [127] concluded that decontamination of implant surfaces by means of the Er:YAG laser did not excessively heat the peri-implant bone within the energy range of 60 to 120 mJ at 10 pulses per second for 120 seconds. The bone interface did not exceed 47°C, the top threshold of osteocyte viability. Kreisler et al [109] examined the ability of the Er:YAG laser to treat peri-implantitis. They concluded that even at low energy settings, the Er:YAG laser has a high bactericidal potential on common implant surfaces. They suggested further clinical studies to justify and evaluate the efficacy of this wavelength in the treatment of peri-implantitis. Schwarz et al [128,129], in two separate studies, examined the effects of the Er:YAG laser on the surface structure of titanium implants. They discovered that using the erbium lasers on implants resulted in no thermal damage, did not damage the titanium surfaces, and did not inhibit or influence the attachment of human osteoblastlike cells to the implants. The role of the erbium family of lasers in periodontics is under examination at this point, and over the next few years, the exact benefits of this wavelength for the discipline of periodontology will become clearer.

Role of erbium lasers in bone ablation

Er:YAG laser ablation has been researched in the medical field, primarily in the field of otolaryngology [130–132]. Caversaccio et al [131] showed that the Er:YAG wavelength was ideal for otologic surgery due to the water absorption characteristics of this wavelength and the precise bone ablation that is provided without the risk of major collateral thermal damage. Bornstein et al [56], quoting the research done by Walsh et al [133], showed that the lateral thermal damage adjacent to the surrounding tissue is 5 to 10 μm.

Truong et al [134], in their article on nasal bone ablation, described two specific criteria that needed to be met to use a particular wavelength on bone. Rapid tissue ablation of bone and an absence of char were the two main criteria cited. The Er:YAG wavelength was shown to produce an excellent cut, and so long as the surface remained moist during ablation and the appropriate settings were used, charring was not seen.

Romano [135] investigated the Er:YAG laser and its ability to cut bone and found that the depth of ablation was linearly related to the number of pulses and that moisture of the surgical site with water spray prevented char formation. In addition, Romano [135] calculated that repetition rates above 20 Hz would not significantly increase the risk of more collateral thermal damage.

Shori et al [136], in a very important study, showed that as the water molecules absorb more of the Er:YAG laser energy, the water temperature increases and the length and strength of the oxygen–hydrogen bonds in the water molecules change. The absorption ability for the water molecule then shifts to wavelengths that are much shorter than that of the Er:YAG (2.94 μm). This shift in the absorption peak for water decreases the effectiveness of the beam to perform ablation of tissue in a controlled thermal fashion. Therefore, the conclusion from this study suggests that it is crucial to (1) keep a continuous water spray on the surgical site to act as a heat sink and (2) keep the energy settings to as low as possible to avoid iatrogenic damage.

In searching for published literature on the role of the erbium family of lasers in the ablation of bone with dental applications, Walsh [123], in an early study, looked at the role of lasers in implants, bone, and soft tissue surgery. Sasaki et al [137] looked at the nature of tissue after irradiation with the Er:YAG wavelength compared with the CO_2 laser and bur drilling. Using scanning electron microscopy and transmission electron microscopy, they demonstrated that laser irradiation of bone resulted in a changed layer of 30-μm thickness, which consisted of two distinct sublayers: a superficial, greatly altered layer and a deeper, less affected layer. They found that the major changes on bone consisted of microcracking, disorganization, slight recrystallization of the original apatite, and slight reduction of the surround organic matrix. In a follow-up study, Sasaki et al [138] looked at the effect that an Er:YAG laser at 100 mJ per pulse and a pulse rate of 10 Hz (1 W) would have on the calvarium bone of rats. Scanning electron microscopic observations revealed well-defined edges and a smear layer–free surface with a characteristically rough appearance and entrapped fibrinlike tissue. No melting or carbonization occurred, unlike the CO_2 laser samples. The conclusion reached was that the Er:YAG laser could become an alternative method for oral and periodontal osseous surgery.

Kimura and colleagues [139,140] provided two studies that looked at the role of the Er,Cr:YSGG laser in the irradiation of canine and bovine bone. In their first study, canine mandibles were irradiated with 5 W and 8 Hz for 10 or 30 seconds. Regular, well-defined grooves were produced and thermography showed that the maximum temperature increase was an average of 12.6°C for the 30-second duration. They concluded that the laser effectively cuts canine bone without burning, melting, or changing the calcium/phosphorus ratio of the irradiated bone.

In the bovine bone study [142], the parameters were 20 Hz with 4 W of power. The investigators varied the position (fixed or variable) and the contact mode (contact or noncontact) and found that minimal thermal damage and precise surgical bone cutting and ablation occurred. They discovered that more thermal damage and greater ablation depth occurred in the samples in which the laser beam was fixed and in contact mode, suggesting that care must be taken to avoid these parameters when using erbium lasers.

These more recent studies confirm the original findings of Eversole et al [41] who concluded in their 1995 article that the Er,Cr:YSGG laser was an effective tool for precise osseous surgery and healing. The laser produced results that were deemed to be comparable to conventional surgical bone wound healing. The investigators concluded that the "wound cavities were smooth, clean and straight" and "at 24 hours, the wound sites for both bur and HKS (hydrokinetic system) showed a clean cut margin with a thin zone of basophilic characteristic of a thermal coagulative effect. This zone measured 40–60 μm." These findings are very similar to those found in the Er:YAG laser in terms of their basic histologic appearance and their wound healing pattern.

In closing, the laser likely is to become much more commonly used in osseous surgery in the future. In the modern clinical practice, the laser can be used routinely for the ablation of bone and for the removal of root tips, osseous recontouring, apical surgery exposure of bony impacted teeth, and other procedures. Continued research into the role of the erbium family laser for treatment around implants and the ideal settings for bone to minimize iatrogenic damage is indicated for the future.

Clinical cases using the erbium:yttrium-aluminum-garnet wavelength in vivo

Clinical tips and cases for restorative dentistry and the erbium lasers

All erbium lasers have the ability to vary the power settings from higher energies that are needed to ablate enamel to lower settings that are needed to ablate dentin, caries, and soft tissue. The higher the water percentage of the target tissue, the lower the energy required to ablate the tissue. Enamel, for example, contains about 3% water, 1% organic material, and 96% inorganic compounds. Healthy dentin is composed of 10% water, 20% organic material, and 70% inorganic material. Diseased tooth structure has a much higher water content and a proportionally lower inorganic content.

Recommended power settings for the erbium family of instruments, as displayed on the panel

Enamel: 4–8 W
Dentin: 2–5 W
Caries: 1–3 W
Bone: 1.5–3 W
Soft tissue: 1–3 W

The erbium laser's usefulness in restorative dentistry has been validated clinically and scientifically over the last few years. These hard tissue lasers are end-cutting devices that require the operator to change the manner in which many of the preparations are done compared with traditional methods using high-speed handpieces. For instance, when treating occlusal lesions, the operator must learn to open up the groove with the laser first. The laser is directed perpendicular to the cuspal slopes that come together to form the occlusal grooves. The movement of the tip should be in slow, lateral movements of roughly 1-mm increments. In addition, plunging movements into the tooth with the tip can be used to help deepen the ablative process. Another useful technique is to use a broader tip initially (eg, 600-μm tip) and then proceed to a smaller tip (ie, 400-μm tip). The smaller tips produce higher power densities for the same settings. The tips always should be kept in slight movement to prevent build up of heat and ablation by-products in the cavity preparation. Kim et al [141] found that the water spray with an Er:YAG laser should be continuous and steady, and their study suggested that the amount of water for optimal ablation should be 1.69 mL per minute for the optimal ablation for 250 mJ of energy per pulse in dentin and enamel. The same flow rate of water was ideal for dentin ablation at 400 mJ per pulse, but the enamel ablation at this higher energy level required a higher water flow of 6.75 mL per minute. These water flow values were discovered to remain constant, regardless of whether the pulse repetition (Hz) was 5, 10, or 20 pulses per second.

The approximate distance that the distal end of the laser should be from the tooth depends on the wavelength, manufacturer, and delivery system. Contact or near contact of quartz or sapphire tips is desirable in fiber optic–delivered systems. The optimal distance for cutting for these erbium lasers is in the 0.5- to 2-mm range away from the tooth. Further defocusing of the tip from the target tissue will attenuate the beam's impact on ablation. This technique is one method of decreasing the power to the target tissue and the relative volume and speed of ablation. If the laser tip contacts the tooth structure, then the laser will cut; however, the degradation of the tip will be faster than if the tip is held in a slightly noncontact manner. In erbium laser systems in which the delivery system is a hollow wave guide, contact tips are available, which makes operative dentistry similar in tactile sensation to using a conventional turbine handpiece.

Determination of the extent of remaining caries in a laser preparation is more difficult than in traditional restorative preparations. The reason is that caries-detector dyes produce false positives on the enamel-etched surface and, therefore, reliance on extremely high magnification of $\times 10$ and above or by tactile means including sharp spoons or small, slow-speed round burs is necessary to confidently determine whether all decay is removed. There is some evidence to suggest that the acoustic popping sounds change depending on whether all decay is removed, but this is controversial. The author has found that the continual flow of water from the erbium lasers hydrates the decay, creating a translucency that can make it more difficult to determine visually whether complete caries removal has been accomplished. The hydration of the decay and laser ablation that occurs seems to make the "peeling" removal of retained caries with sharp spoons easier than when the laser is not used.

Care must be taken when using the laser to not create narrow troughs the approximate width of the laser tip. Preparation of narrow troughs blocks the water flow to the ablated area and, in turn, creates charring of tooth structure, a stalling of the ablation process, and pain due to heat buildup. Care also must be taken to ensure that water flow to the ablation site continues and is not hindered by inadequate water or air spray that can occur when the tips are not screwed in properly, the air/water supply is not adjusted properly, or through overaggressive suctioning by the dental assistant, which in turn can prevent water cooling of the site and direct flow of the water spray into the suction.

Many clinicians have noted that even deep restorations at times can be completed without anesthetic. The laser seems to produce a temporary partial anesthesia or "numbing "of the tooth being lased. In fact, several clinicians have suggested that the erbium lasers can be defocused at high energy (5–6 W) for up to 2 minutes to help decrease the sensitivity of the laser preparations. Others have described a procedure of gradually increasing the energy levels from very low settings (0.25 W) upwards as an effective method of avoiding overt sensitivity. Both techniques are taught by major laser manufactures as a possible means of "laser anesthesia," which can be used even in combination with high-speed handpieces to remove existing amalgam restorations before removal of recurrent decay by way of the lasers. Extreme caution must be taken to avoid contact of erbium laser energy with amalgams because this can release mercury into the environment, and with some wavelengths, the resulting sparking that can occur may lead to maintenance issues, with degradation or destruction of fibers, wave guides, and handpieces. Careful adherence to the manufacturer's instructions can prevent costly and time-consuming repairs.

Other clinicians are using the bactericidal effects of the erbium lasers to reduce the likelihood of bacteria remaining in the dentinal tubules before filling the preparation, regardless of whether it was completed with traditional high-speed handpieces. The laser used in a medium power setting of 2 to 3 W can remove the smear layer in dentin effectively and provide for a disinfected dentin surface to bond to. Postoperative sensitivity may be decreased for some of these restorations. Sharon-Buller et al [142] showed that Er:YAG laser cavity preparations had greatly reduced bacterial levels compared with preparations completed with handpieces.

Proximal tooth surfaces adjacent to the laser preparation should be carefully isolated. Metal matrices are ideal because the laser does not have an effect on the metal surface. This inability of the laser to interact with metal surfaces makes this technology ideal for the preparation of recurrent decay gingival to the margin of a porcelain or full metal restoration; the laser literally tracks and removes the decayed area without affecting the existing restoration. The same is not true in the presence of composite restorations because the erbium family of lasers can remove composite, compomer, and glass ionomer restorations.

The speed of removal of these tooth-colored restorations is dependent on the age of the restoration and the filler amount. Preparations completed with the Er:YAG and Er,Cr:YSGG wavelengths are best restored with either composite resins or glass ionomer materials. Amalgam is not the ideal material for the roughened preparation that is created with lasers.

Tips are reusable but must be discarded eventually because they will chip and degrade with continued use, often after 30 to 50 patient visits. High magnification can allow for the operator to repolish the tip with a porcelain polishing system to lengthen the lifetime of a tip. The efficiency in ablation of a tip after polishing can be expected to decrease somewhat compared with a new tip.

In closing, the erbium family of lasers have been used for a multitude of restorations of all types, but more recently, the role of this wavelength in other areas such as for soft tissue removal and recontouring has gained a larger focus in the academic and clinical realms.

As with any dental procedure, there are various alternatives to obtain an excellent clinical result, and the following clinical cases are a brief attempt to show the capabilities of the erbium wavelengths for cavity preparations, soft tissue surgery, and osseous recontouring. Many other procedures are possible with this wavelength family, and these examples are meant only as an introduction to the role of hard tissue lasers in private practice.

The following clinical cases were treated by the author in his practice and documented through high-magnification digital photographs obtained through a dental operating microscope at magnifications between ×2.5 to ×16 power. None of the photos have been digitally enhanced other than to resize them for publication purposes. The procedures were performed with the Hoya Con Bio DeLight device, wavelength 2940 nm. The parameters noted are specific to this device.

The author encourages professional training through courses provided by experienced clinicians who may offer specific advice for the particular brand of hard tissue laser that the clinician has purchased.

Clinical case 1: erbium laser for microdental caries removal

These cases are best diagnosed with the DIAGNodent (KaVo America Corp., Lake Zurich, Illinois) because early dentin caries show up as values from around 20 to 40. Unlike using a high-speed bur for these early occlusal fissure lesions, the lesions must be opened up with the laser tip positioned at right angles to the cuspal slopes of the enamel as they come to the fissure groove. When treating these cases, the cuspal slopes (ie, facial) on one side of the groove are approached as in Fig. 1, and then the other side's cuspal slopes are treated before dropping perpendicular to the groove.

High power settings of 4 to 6 W with high amounts of water and air should be used. The air often can be slightly less than the amount of water to create a fine spray. Caries removal can be confirmed with small, round slow-speed burs. High-magnification systems such as high-powered loupes or microscopes can aid in viewing the texture of the dentin or caries-detector dye may be used, with the caveat that caries-detector dye can cause false positives within the etched enamel.

Flowable resins are best used to restore these lesions, and laser analgesia often can be obtained, if necessary, by positioning the laser at high-power settings (6 W) in a defocused manner just off the lesion so as to not cut the tooth but bathe it in energy for 90 to 120 seconds.

Isolation with rubber dam and copious amounts of topical anesthetic creams can help with the retainers. Another alternative is the ISOLITE (Isolite Systems, Santa Barbara, California), which can be used effectively to provide a dry field for resin restorations to be placed.

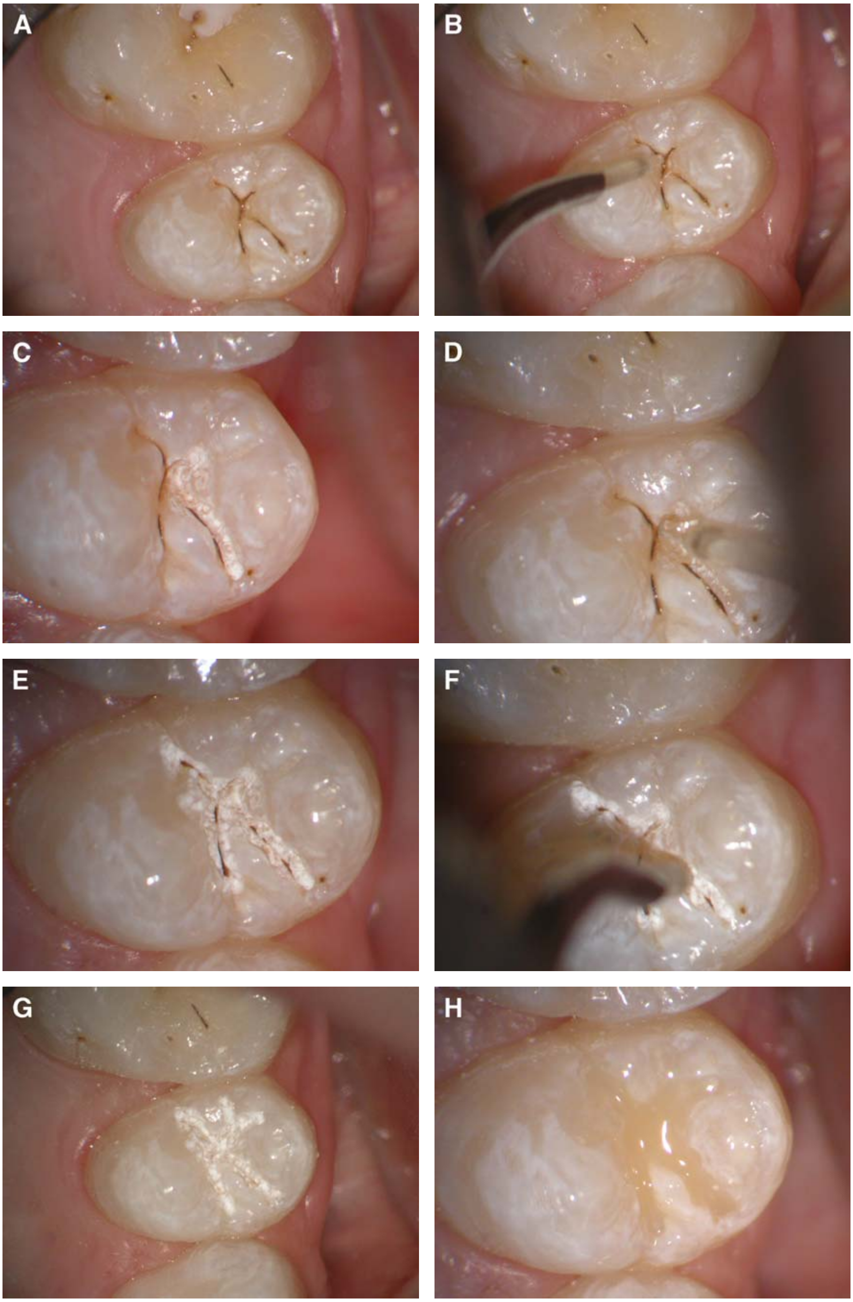

Fig. 1. (*A*) Preoperative view of premolar. (*B*) Angling of tip perpendicular to facial cuspal slope. (*C*) Facial cuspal slope treated. (*D*) Angle of laser to lingual cuspal slope. (*E*) Lingual cuspal slope treated with laser. (*F*) Laser perpendicular to occlusal groove. (*G*) Occlusal preparation complete. (*H*) Completed restoration.

Clinical case 2: erbium laser for large occlusal lesions

In this large occlusal lesion, isolation was obtained with an Isolite on a 5-year-old girl (Fig. 2). No anesthetic was used, and laser analgesia, with a defocused beam at 1 cm at 6 W for 120 seconds, was used for each molar. Final caries removal was completed with small spoons, and Fuji IX (GC America Inc., Alsip, Illinois) was used as the restorative material.

Enamel cavosuface margin was treated for 90 seconds per tooth at high power settings of 4.8 W (30 Hz, 160 mJ, with water and air spray), and

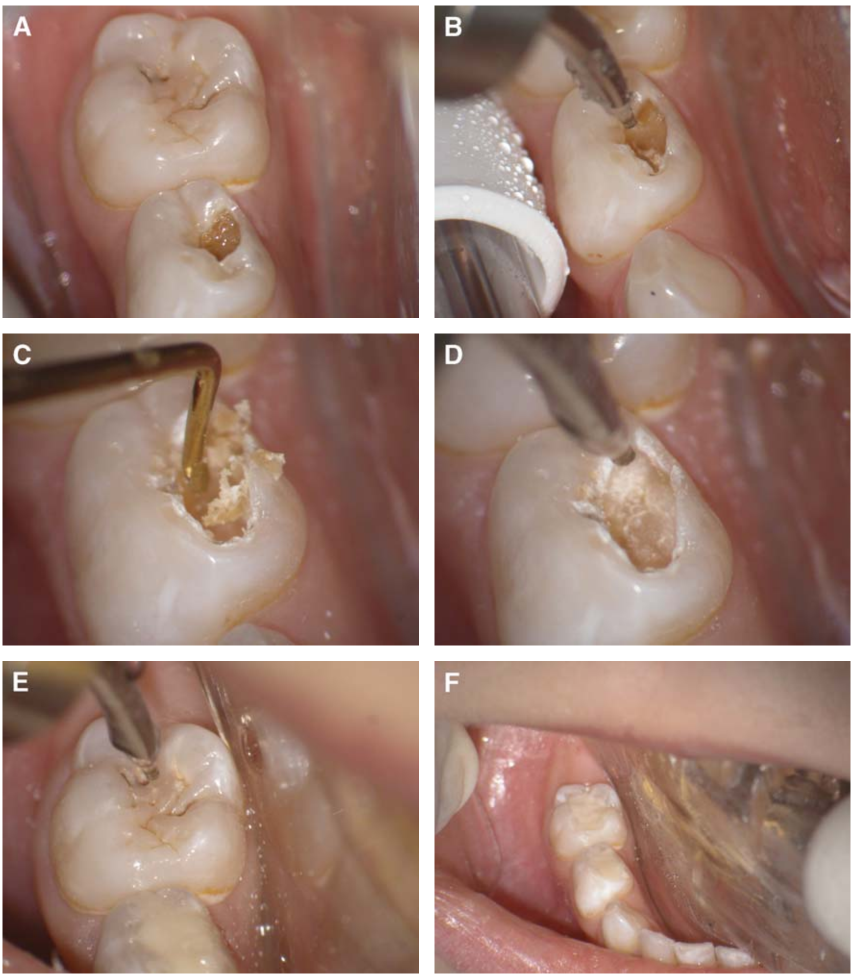

Fig. 2. (*A*) Preoperative high magnification view (×10) of caries. (*B*) Erbium laser set to fire on first primary molar. (*C*) Small spoon to remove soft caries. (*D*) Laser at 30 Hz and 60 mJ to remove smear layer. (*E*) Laser at high settings for enamel on second primary molar. (*F*) Restorations completed.

deeper caries were removed with moderate settings of between 2 and 4 W (30 Hz, 60 mJ to 30 Hz, 100 mJ, again with water and air).

Clinical case 3: erbium laser for class II caries

In class II carious lesions in children or adults, care should be taken to isolate the adjacent tooth from iatrogenic damage. Metal matrices (tofflemire bands, T bands, or thick metal sectionals like Ultraguard (Ultradent Products, South Jordan, Utah) serve as barriers to prevent the laser from affecting adjacent interproximal areas.

High power settings (4–6 W) are necessary to gain penetration of enamel, and the outline of the preparation should be completed as best as possible in enamel before entering dentin. If local anesthetics are not used, then settings most often need to be lowered when reaching the dentin–enamel junction. Careful caries removal can be completed again, often without anesthetic through judicious use of round burs or spoons, and often, if the laser is used for a period of 3 to 5 minutes, then some short-term "laser analgesia" allows for completion of the caries removal without the need for local anesthetic (Fig. 3).

It has been the author's experience that class II preparations are easier to complete without anesthetic in the pediatric dentition. Some clinicians using high magnification are able to prepare marginal ridges very conservatively using tunnel preparations in early interproximal lesions.

Clinical case 4: erbium laser for class III composite resin and caries removal

Class III erbium laser preparations allow the clinician the opportunity to provide anesthetic-free procedures in an area where patients are most appreciative of not being given local anesthetic. The erbium laser can be used at medium-to-high power settings (2–6 W, with water and air) to remove composite restorations, depending on the sensitivity of the patient. Higher settings have been noted to be necessary to remove higher filled composites. The laser seeks out the resin component of the composite and, therefore, it seems as if microfills are easier to remove than highly filled hybrids or packables.

As with class II preparations, adequate protection of adjacent enamel and dentin is required. After the composite is removed at higher settings, the energy may be reduced for caries removal and for placement of an enamel bevel. Care should be taken when creating this bevel to use medium settings (2–4 W in a defocused manner) or, better yet, to use low settings (below 2 W; 30 Hz, 50–60 mJ) in contact mode to prevent excessive ablation craters from appearing. After placement of the facial bevel, the clinician should ensure that the ablation is not visible when wet and the chalky enamel appearance is visible only when the tooth is dried or that the bevel must be gently

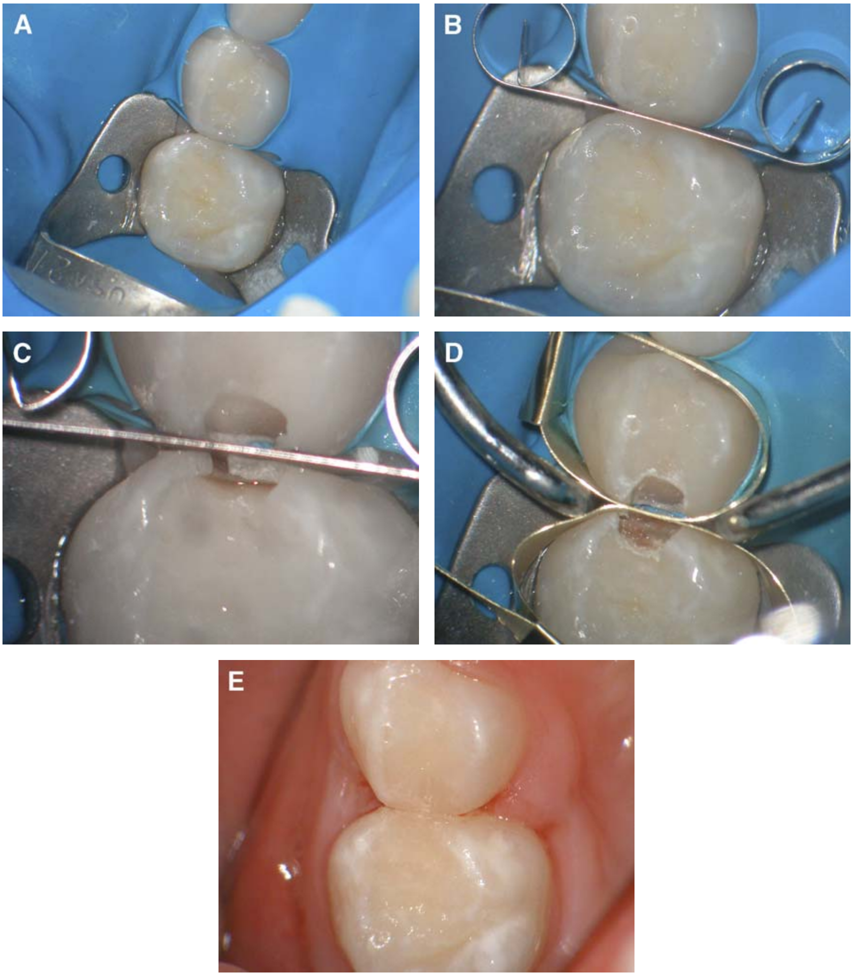

Fig. 3. (*A*) Preoperative photograph of primary interproximal lesions. (*B*) Isolation with Ultradent Interguard metal matrix. (*C*) Preparation on primary second molar in progress. Note decay on mesial of first primary molar. (*D*) T bands in place for restorative material. (*E*) Restorations completed.

scraped with a spoon or resurfaced with air abrasion or a diamond to remove loose enamel prisms that will affect bonding (Fig. 4). The higher the power settings and the closer the tip to the enamel, the greater the potential for the ''white spots '' of ablation to show through the resin.

Clinical case 5: erbium laser for class IV composite resin and caries removal

When using the laser for preparation of class IV lesions, the laser can be an extremely beneficial adjunct to traditional therapy. The laser can be used

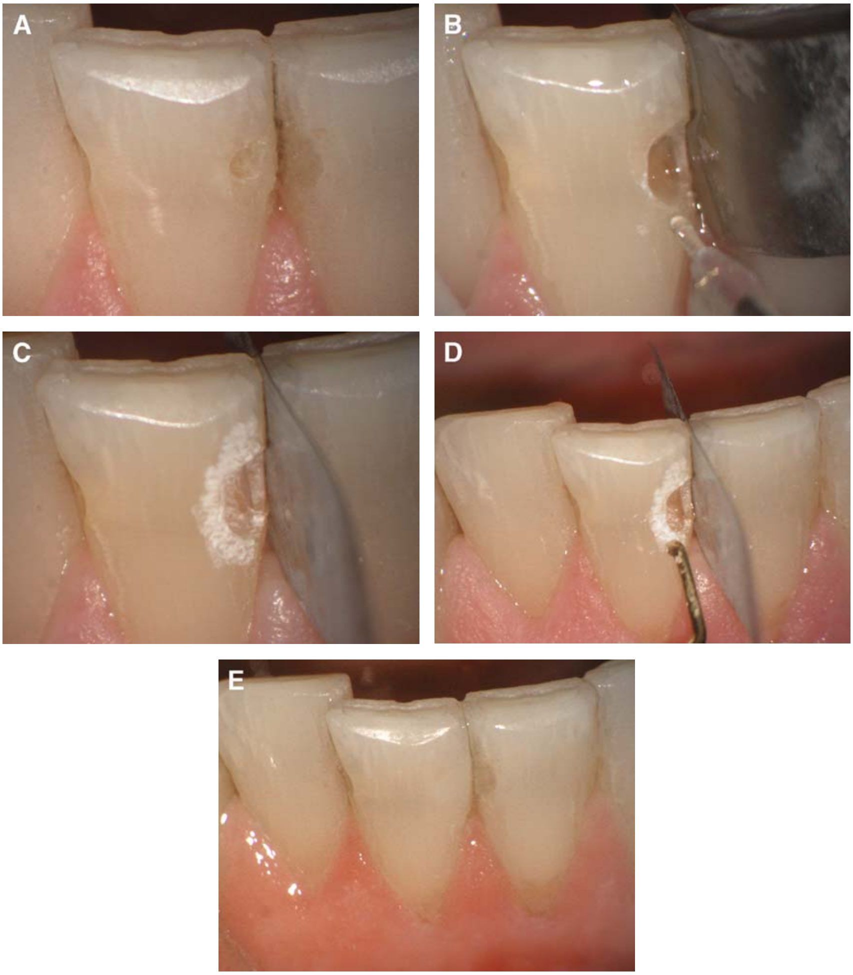

Fig. 4. (*A*) High magnification view (×10) of leaking resin restoration requiring replacement. (*B*) Metal band placed. Composite removed and laser aimed for bevel placement (30 Hz and 50 mJ). (*C*) Bevel completed and surface dried out for inspection. (*D*) Small spoon for removal of loose enamel prisms. (*E*) Restoration completed.

to create a long bevel that can greatly facilitate enamel bonding by increasing the surface area. As with class III preparations, care must be taken to idealize the bevel and prevent ''shine through'' of the laser ablation on the facial. Gentle scraping of the loose prismatic enamel or confirming that when wet, the ablation does not become visible eliminates the concern of ''shine through'' after the restoration is completed (Fig. 5).

The opportunity to prepare teeth quickly and without anesthetic often is apparent when working on class IV anterior preparations, and patients enjoy the ability to proceed without local anesthetic in the anterior region of

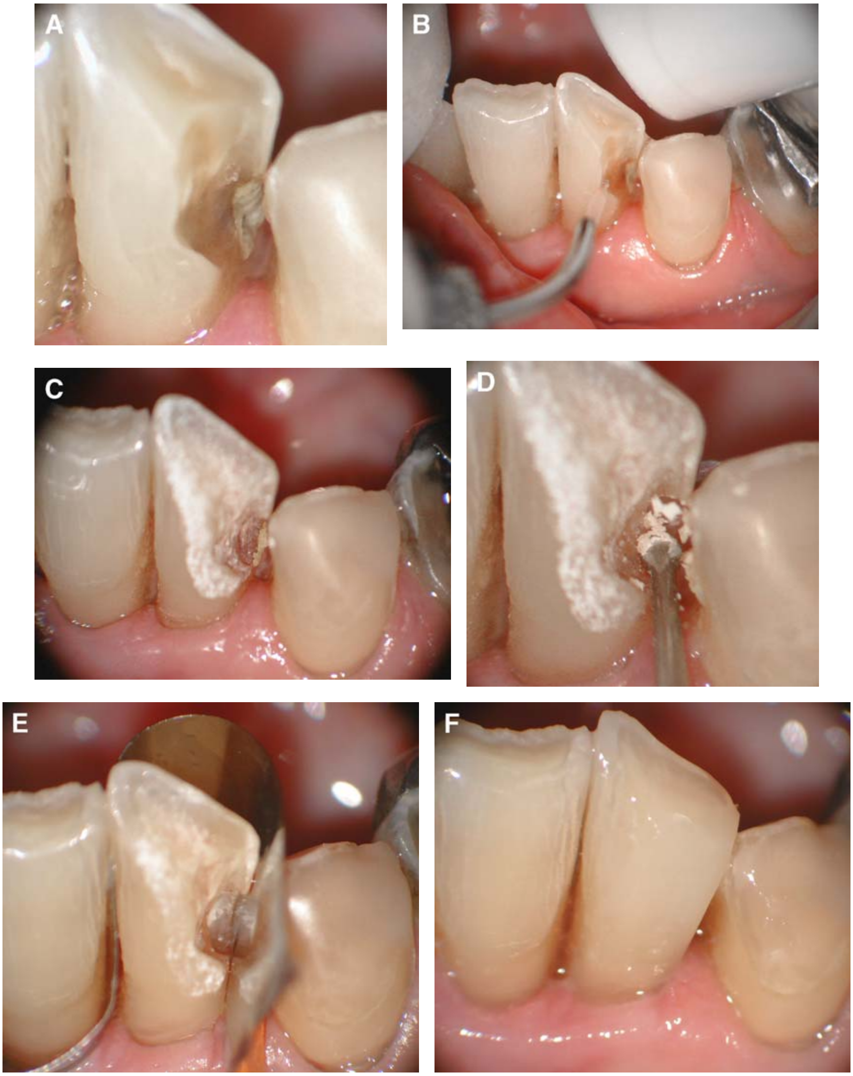

Fig. 5. (*A*) High-magnification view (×16) of tooth. (*B*) Four hundred–micrometer laser tip to remove caries and bevel facial surface (30 Hz, 50–140 mJ). (*C*) Preparation nearly complete. (*D*) Small spoon to remove remaining decay. (*E*) Matrix in place on tooth. (*F*) Restoration completed.

the oral cavity. Lower anterior preparations involving the incisal edge optimally are treated with the laser because the risk of fracturing the buccal or lingual enamel ridges is reduced compared with treatment using a high-speed handpiece. Small spoons or slow-speed round burs can be used to confirm complete decay removal.

Clinical case 6: erbium laser for class V abfractive lesion with soft tissue removal

The treatment of cervical root caries, abfractive lesions, and gingival recession is ideal with the erbium laser because most times, the restorations can be accomplished without local anesthetic (Fig. 6). Laser desensitization of sensitive areas can be accomplished with very low settings (ie, 0.25–0.5 W, without water but with gentle air) in a defocused manner, with gradual progression toward the tooth until the patient feels sensitivity. Repeated two to three times in immediate fashion, many patients will find improvements in root sensitivity that often can be prolonged.

In situations in which preparation of the root surface is necessitated due to abfractive lesions or caries, low-to-medium settings of energy are all that are needed, particularly for those areas on dentin or cementum. The clinician can start with very low settings initially (0.3–1 W, with water and air) to build the patient up to the cold air and water that are used (warm water in the reservoir bottle can decrease the initial sensitivity). The clinician also may use the laser in a defocused mode initially and gradually move into contact to again acclimatize the patient to the laser.

In situations in which there is gingival tissue "slumped" into the lesion and when this tissue is not overly inflamed, the erbium laser can remove the tissue easily, most times without anesthetic. The hard tissue lasers "plane" or "shave" the tissue away almost layer by layer, providing precise control of exposing the gingival aspect of the lesion. A crucial tip is to make sure that angulation of the laser tip when removing gingival tissue is parallel to the long axis of the tooth or perpendicular to the gingiva. This angulation of the tip will prevent iatrogenic notching of the root surface that can occur when using an approach as if one were using a soft tissue diode (Fig. 7) The clinician must be conscious of the nonselectivity of this wavelength for soft tissue, bone, dentin, and cementum when positioning the tip near or into the gingival sulcus.

In addition, inexperienced laser clinicians are encouraged to place silk suture into the sulcus initially to aid in determining the amount of tissue that is removed with a gingivectomy. Principles including the concept of biologic width infringement must be contemplated any time a gingivectomy is performed with the laser.

Settings for soft tissue removal can range between 0.3 to 1 W (10 Hz, 30 mJ to 30 Hz, 30 mJ); often, the patient can tolerate these settings without anesthetic. Unlike dedicated soft tissue lasers, hemostasis, particularly in inflamed tissue, can be an issue with this wavelength. If coagulation is deemed to be an issue, then the clinician may decide to choose an alternative wavelength or method for isolating the gingival aspect of the preparation. Contrary to many reports, cases treated with a variety of hard tissue lasers seem to have minimal differences in the coagulation capabilities. This result is borne out by analyzing the absorption spectra of various chromophores

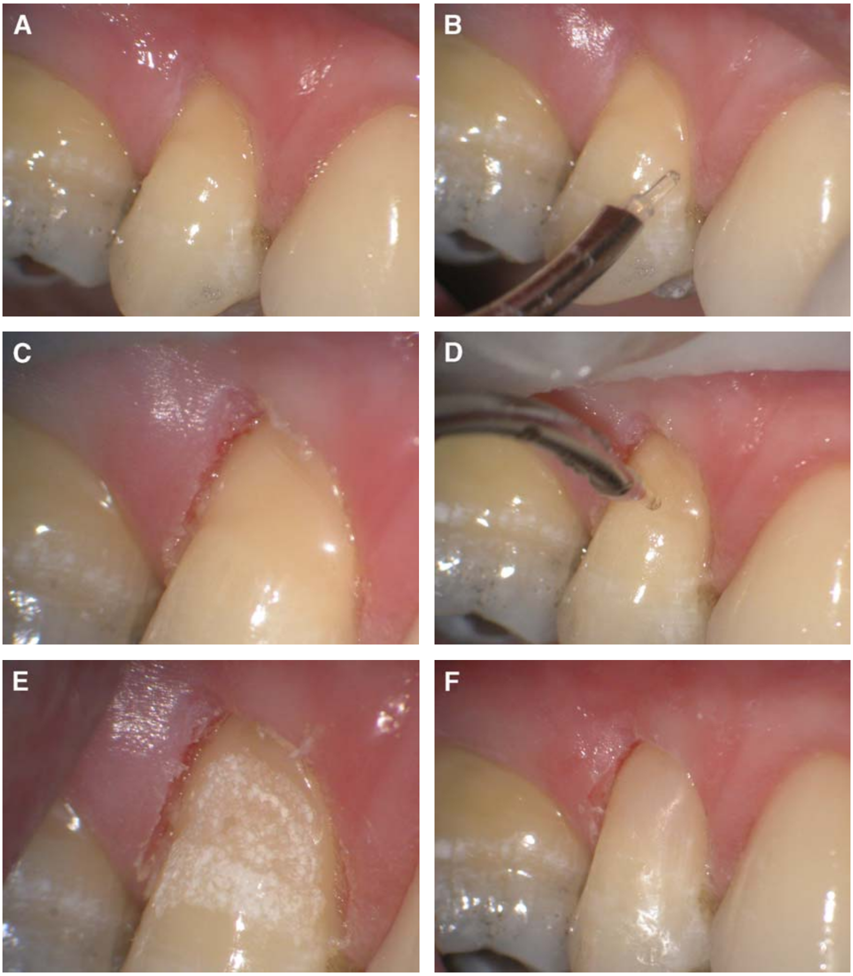

Fig. 6. (*A*) Preoperative photograph of abfractive lesion with sensitivity. (*B*) Angulation of laser tip for soft tissue removal (parallel to root), with settings of 20 Hz, 30 mJ, 0.6 W, and with very little water and slight air. Topical only. (*C*) High-magnification view (×16) of the soft tissue removal with the laser. (*D*) Angulation of tip for dentin, cementum, and enamel removal (perpendicular to surface), with settings of 30 Hz, 30 to 50 mJ, and with water and air 0.5 to 1 mm out of contact. (*E*) High-power photograph of preparation completed. (*F*) Final restoration completed (×4 magnification).

such as water, hemoglobin, and melanin and in understanding the role of various pulse durations toward coagulation capabilities. If there is a difference among erbium laser brands in coagulation capabilities, then it is very minor. It is undisputable that near-infrared wavelengths (argon, diodes, and Nd:YAG) have superior capabilities with respect to coagulation, but in many instances, they are less comfortable when used

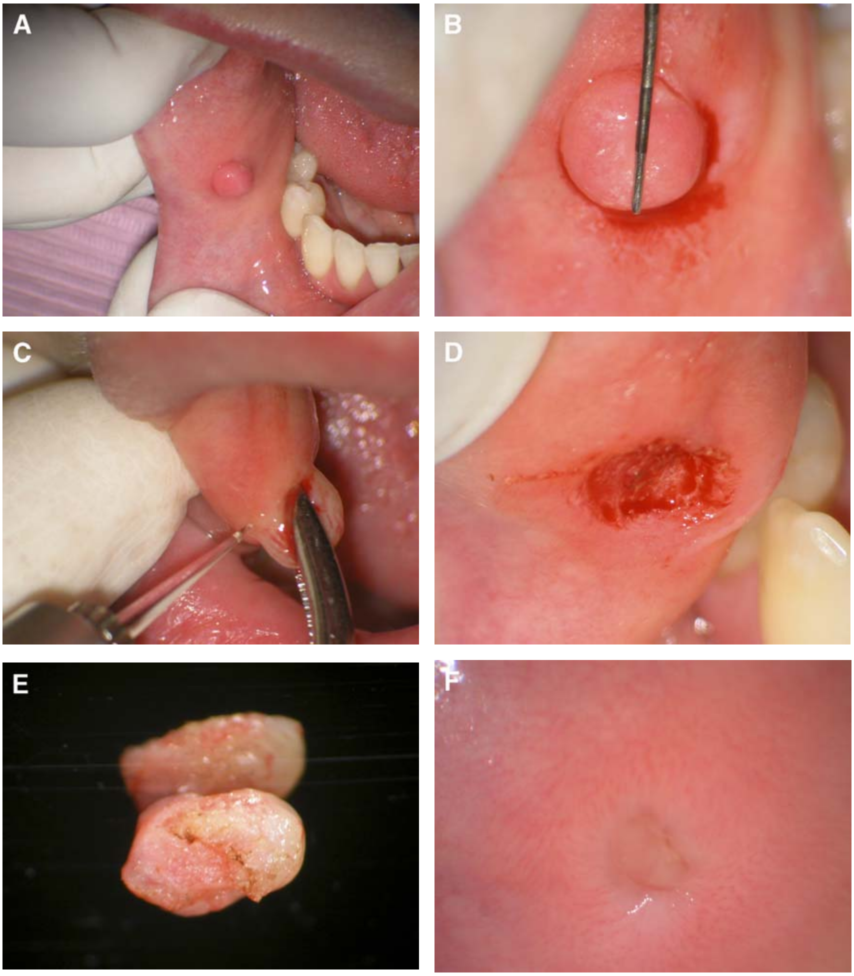

Fig. 7. (*A*) Preoperative photograph of fibroma on right buccal mucosa. (*B*) Fibroma measuring 6 to 7 mm in diameter. (*C*) After anesthetic, grasping lesion with hemostats. (*D*) Tissue was excised, but coagulation was not achieved. Pressure applied to site. (*E*) Tissue sample to be sent to pathologist for histologic evaluation. (*F*) High-magnification view of healing at 72 hours.

clinically without anesthetic on soft tissue unless the lasers are placed in gated or pulsed format. This sensitivity in soft tissue has to do with the thermal relaxation time of the tissue to cool from the thermal insult and is one reason why the very short pulsed erbium lasers are used for soft tissue more often without anesthetic.

In summary, the soft tissue component of class V lesions, when treated with the erbium laser, often may be treated without sensitivity but can create difficulties with coagulation in tissue that is inflamed to begin with.

Because microleakage and bond strength studies have shown inconsistent results in the published literature, when using the laser, clinicians are advised to pay attention to providing mechanical retention in their preparation design or to add a bevel on enamel wherever possible. Dentin bonding is mediocre at best with any treatment regimen, and this is no different when using lasers.

Suggested settings for class V lesions

Soft tissue removal: low power (0.3–1 W; 10–30 Hz, 30–50 mJ), contact to slightly out of contact, with water off or very low and with air on slightly to cool tissue. Some water spray from the air/water syringe will prevent tissue accumulation on the tip (‘‘cotton candy effect’’).

Caries, cementum, and dentin removal: low-to-medium power (0.6–2.5 W), contact to slightly defocused, with water and air. Cementum and dentin may need slightly higher settings to ablate than caries. Settings are dependent on a number of variables, including age of patient, general sensitivity to air and water, depth of decay, tip diameter, proximity toward pulp, degree of calcification of pulp chamber, and distance of tip from surgical site.

Enamel bevel: medium power (1.5–3 W), slight noncontact in most cases, with water and air.

Clinical case 7: erbium laser for fibroma removal on buccal mucosa

The use of the hard tissue laser for soft tissue applications is possible with consideration of the possible unwanted side effects that may occur. By using moderate settings with the erbium laser and allowing the energy to be absorbed by water molecules in the tissue, this wavelength can be used effectively to ablate soft tissue. The two main negative sequelae that must be identified and considered for any procedure using the erbium laser family are that there is not selectivity for soft tissue and that coagulation with this wavelength is not as ideal as with a dedicated soft tissue laser such as a diode, Nd:YAG, argon, or CO_2 unit. The erbium wavelength, even at low settings, quickly ablates and cuts soft tissue with minimal damage to adjacent tissue and, in many instances, with minimal or no local anesthetic.

In this case, a young female patient had a small fibroma on the buccal mucosa that she wished to have removed (Fig. 8). The patient wished to be anesthetized, and a small amount of local anesthetic was infiltrated into the adjacent area. The fibroma was removed with a soft tissue tip, with settings of 30 Hz and 80 mJ (2.4 W). If anesthetic had not been given, much lower settings would have been used (in the range of 0.4–1 W).

Very little water is necessary and a gentle air flow helps to keep the tissue cool, as does the proximity of high volume suction. In ablating lesions that may be viral, extreme caution must be exercised to avoid inhalation of the

Fig. 8. (*A*) Preoperative photograph of thick maxillary frenum. (*B*) High-magnification view of frenum pull with soft tissue Er:YAG tip. (*C*) Frenectomy ablated labial view. (*D*) Frenectomy ablated lingual view. (*E*) Two-week view of palatal healing. (*F*) Two-week view of labial healing.

viral plume. High-volume suction and fine filtration laser masks should be employed, with appropriate laser safety glasses.

Heavily inflamed tissue such as hemangiomas are not primary candidates for treatment with this wavelength, and coagulation during soft tissue ablation can be challenging when using any of the lasers in the erbium family. Healing is uneventful and the risk of unwanted charring at low-to-moderate energy settings is minimal.

In this case, the fibroma was removed quickly with the aid of a hemostat, and the healing at 3 days was remarkable. The area where the tissue was excised was asymptomatic from the time the anesthetic disappeared, and the pathology report for the biopsy was returned and diagnosed histologically as a fibroma.

Clinical case 8: maxillary labial frenectomy with erbium laser

The judicious use of laser technology to remove maxillary and mandibular labial and lingual frena has been accomplished successfully with many wavelengths including diode, CO_2, and Nd:YAG lasers. In considering the role of a hard tissue laser for ablation of soft tissue—and specifically for cutting frena—the clinician must understand the relative lack of coagulation and hemostasis that occurs with this wavelength. In addition, the clinician must keep in mind the ability of this wavelength, due to its short pulse duration and limited depth of penetration, to rapidly ablate soft tissue while causing minimal lateral thermal damage compared with dedicated soft tissue lasers. In addition, due to the short pulse duration, many clinicians can complete frenectomies and other soft tissue surgeries using little-to-no anesthetic without major discomfort to the patient.

Clinical protocol

The removal of the maxillary frenum with the erbium laser can be accomplished with topical anesthetic cream only and with minimal or low power settings (0.4–1 W). It will take longer to cut at these energy settings (20 Hz and 30 mJ) but the dentist often can complete the procedure without local anesthetic. If the clinician wants to control the hemostasis or proceed faster, a drop of anesthetic can be used with medium power settings of 2 to 3 W (30 Hz and 80 mJ, with air and a limited amount of water). The technique is the same as when using a blade: the upper lip is gripped with one hand and stretched out and the laser begins the cutting process where the frenum joins the attached tissue (Fig. 9). As the laser is activated, the lip is gently pulled backward, which in effect ''releases'' the frenum, creating a V-type incision as the laser cuts. Often, the hemostasis issues begin when the last fibers have been released. High magnification helps in determining whether all the fibers have been released. If there is transgression of the frenal fibers through to the palate, then a decision must be made to remove these by ablating the papilla down to the periosteum or to create a palatal wedge or incision down to the periosteum to release the fibers connecting through to the palate. Healing occurs uneventfully on these frenectomies, and postoperative medication often is limited to the first day (if needed at all).

Clinical case 9: erbium laser for sectioning of a tooth during extraction

The hard tissue capabilities allow the erbium family of lasers to be used effectively to remove enamel, dentin, cementum, and bone. The opportunity to use the laser for the removal of bone and cementum allows it to be used effectively during extractions of root tips. The erbium laser used with water

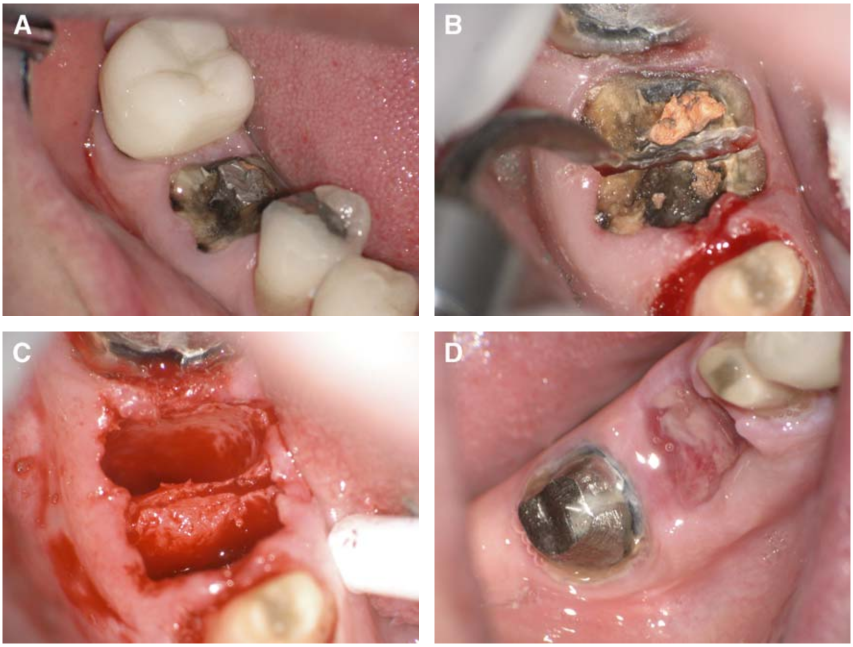

Fig. 9. (*A*) Preoperative photograph of broken, unrestorable lower molar. (*B*) Tooth sectioned with erbium laser at 30 Hz, 160 mJ, 4.8 W, with air and water. (*C*) Tooth successfully removed and the furcal bone contoured with the laser. (*D*) Healing after 7 days.

irrigation is able to ablate tooth structure and bone and minimize damage to both. The water carries the ablation by-products away and the laser sterilizes as it works. The clinician should proceed carefully because this wavelength has no selectivity to hard tissue and iatrogenic damage to adjacent tissues can occur.

Clinical protocol

In this case, the patient had fractured an existing crown at the gingival margin on a lower right first molar (Fig. 7). After consultation, the patient chose to extract the remaining roots and replace the missing tooth with a bridge. The remaining roots of the fractured molar were removed by first sectioning the tooth at high power with a 400-μm tip at high settings (30 Hz and 160 mJ). After luxation of the roots, it was observed that slight notching without charring of the furcal bone had occurred. The healing of the extraction sockets and replacement of the edentulous area was uneventful.

Clinical case 10: erbium laser for ablation of bone

The most recent use of erbium lasers in the dental office is for the precise ablation of bone. The role of the erbium laser in the removal of bone for extractions, exposure of impacted teeth, pilot holes for implant surgery, closed- and open-flap osseous surgery for crown lengthening procedures, and apicoectomies and root amputations has made the erbium laser a valuable tool for ablation of bone. The surgical precision of the laser, combined with the sterilization of the ablation area, has made it a novel and useful adjunct for clinicians who are removing bone.

The clinician should remain cautious when using the laser for bone removal and constantly monitor water flow to make sure that adequate cooling occurs. In addition, to reduce the risk of air emphysema, the dentist must keep the air pressure as low as possible when working around flaps and fascial planes.

A medium setting (2–4 W) is ideal for working on bone, with more energy needed to ablate cortical bone than bone with marrow spaces. The visibility of the surgical site makes lasers ideal instruments for delicate surgeries compared with surgery using a high-speed handpiece in which hemostasis and splatter makes it difficult to visualize the surgical site during surgery.

For ablation of bone, larger diameter tips are ideal for removal of bone. Six hundred–micrometer tips or chisel tips remove more bone per pulse than smaller tips. The larger diameter tips can be used at higher energy settings than smaller diameter tips due to the inverse relationship between power density and spot size. There has been much discussion in the professional community regarding the validity and necessity of closed-flap osseous surgery (no flap raised) versus open-flap surgery. In select instances when minimal amounts of bone are removed, raising of a flap may not be necessary. This closed-flap ostectomy becomes most useful in instances when the reduction of osseous structures is necessitated during a full crown or onlay procedure in which biologic width may be invaded.

Its is the author's finding that closed-flap surgery should be undertaken with caution to reduce the risk of troughing bone and iatrogenically creating periodontal pockets. Full circumferential closed-flap osseous crown lengthening surgery, interproximal removal of bone around margins, and large anterior crown lengthening cases are not ideal cases (in this author's experience) for closed-flap surgery. There are instances, however, when a minor amount of reduction of osseous structure by way of closed-flap surgery may yield excellent results.

Clinical case 11: closed-flap osseous crown lengthening

In this case, the author attempted to heroically salvage a badly decayed tooth with large, recurrent buccal decay beneath the margin of the crown on the lower right second molar (Fig. 10). The patient presented with pain in an emergency situation, and after removal of the crown, extensive buccal decay was noted on the labial.

Removal of the decay under local anesthetic indicated a pulpal exposure and uncertainty as to the prognosis of the tooth. Initial attempts to isolate the gingival margin of decay with a diode laser at 1.0 W proved unsuccessful because the margin of the preparation was still below the soft tissue. The diode laser was used to coagulate the exposed pulp stump at 1.0 W of power. An erbium laser was used perpendicular to the sulcus and parallel to the

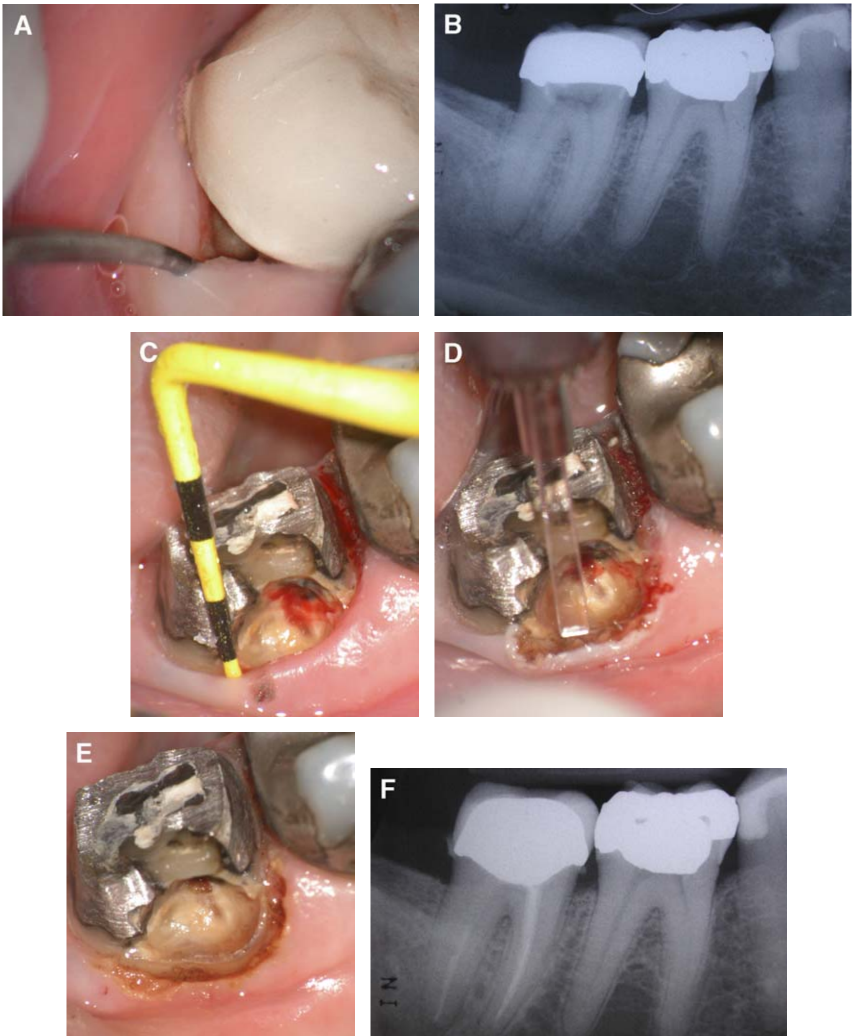

Fig. 10. (*A*) Preoperative view of buccal caries. (*B*) Preoperative radiograph. (*C*) Periodontal probe showing inadequate biologic width after caries were excavated. Endodontic treatment was necessary due to pulpal exposure. (*D*) Erbium laser used to remove facial bone. (*E*) Osseous and soft tissue troughing completed. (*F*) Final restoration placed. (*G*) Radiograph of final restoration.

Fig. 10 (*continued*)

tooth at 30 Hz and 100 mJ (3 W), with water and minimal air for 120 seconds with a chisel tip. A minimal amount of bone was removed on the labial, and a provisional restoration was placed to seal the tooth in preparation for endodontic therapy.

The patient completed endodontic therapy, a post and build-up were provided, and the final margins were placed for the full coverage restoration.

At the final appointment, the full coverage restoration was cemented. Subsequent appointments have determined ideal healing on a tooth that initially had a very guarded restorative prognosis.

In many instances, the requirement for full visualization of the surgical site precludes the opportunity to do closed crown flap osseous recontouring, and the author again cautions users of erbium lasers to follow established protocols and biology when using any erbium laser for the removal of bone.

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