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**The Journal of Laser Dentistry**  
The mission of the **Journal of Laser Dentistry** is to provide a professional quarterly journal that helps to fulfill the goal of information dissemination by the Academy of Laser Dentistry. The purpose of the **Journal of Laser Dentistry** is to present information about the use of lasers in dentistry. All articles are peer-reviewed. Issues include manuscripts on current indications for uses of lasers for dental applications, clinical case studies, reviews of topics relevant to laser dentistry, research articles, clinical studies, research abstracts detailing the scientific basis for the safety and efficacy of the devices, and articles about future and experimental procedures. In addition, featured columnists offer clinical insights, and editorials describe personal viewpoints.
Every time a clinician turns on a laser and picks up a handpiece to use in laser dentistry he or she is about to test first-hand the effect of laser-tissue interactions. Books have been written on this topic and research continues around the world. Even now we do not understand all the nuances of all the factors involved, such as tissue composition, laser wavelength, other laser parameters, exposure duration, energy, delivery system, and so on. The clinician has to rely on the knowledge that others have accumulated and his or her own training and experience to get the best use of the laser for the health of the patient.

Laser-tissue interactions that are relevant to the current use of lasers in dentistry revolve around transmission, scattering, reflectance, and absorption. Much of what we do in practical laser dentistry is brought about by heat generated from the interaction of specific wavelengths of light with one or more components of the tissue that we are “treating.” In order for heat to be generated at the correct level, in the right place, and for the right time, the light from the laser in use must be efficiently absorbed by one or more components of the tissue. Without this absorption we have the wrong laser for the application in mind.

Dentin and enamel contain minerals, water, proteins, and lipids. An understanding of the interactions of these components with each of the available lasers is very important not only for the research community and the developers of lasers, but also for the end user, the clinician, in the dental office. Soft tissues are very different, but again the components such as water and hemoglobin can be exploited for efficient and effective absorption of laser light and conversion to heat for cutting or contouring, for example.

If we want to use laser light as a diagnostic tool for hard or soft tissues, the wavelength must be chosen such that it is transmitted through sound tissue and be scattered or fluoresce in the pathological tissue. Much is known about the various wavelengths and how they interact with the tissues that we deal with in dentistry. In the future new and exciting applications will be available, and more effective variations of current applications will become commonplace. The guest editorial by Dr. Craig Gimbel briefly addresses those thoughts.

In this issue, there is also a position statement from the Academy of Laser Dentistry (ALD) on several aspects of laser interactions with hard tissue. This is the first of several that will be prepared over the coming years by the Science and Research Committee of ALD to address various aspects of clinical laser dentistry. The article is the first step in this direction. Practical issues such as how to best deliver the right wavelength with the right conditions can be affected by how the laser is used. A research article by Dr. Wayne Selting addresses one such problem. Clinical cases that revolve around laser-tissue interactions further illustrate how important is a basic understanding of the mechanisms involved in deciding how to deal with specific cases clinically.

Please enjoy this issue of the Journal. Feel free to e-mail me with suggestions, criticisms, or compliments at jdbf@ucsf.edu.
Dr. Featherstone has no personal financial interest in any company relevant to the Academy of Laser Dentistry. He consults for, has consulted for, or has done research funded or supported by Arm & Hammer, Beecham, Cadbury, GSK, KaVo, NovaMin, Philips Oralcare, Procter & Gamble, OMNII Oral Pharmaceuticals, Oral-B, Wrigley, and the National Institutes of Health.

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Few things in life feel sweeter than investing in the lives of others, then watching them grow and succeed as a result of your efforts. As the 2007-2008 President of the Academy of Laser Dentistry, I am passionate about helping members achieve their professional educational goals as they pertain to lasers in dentistry. The Academy of Laser Dentistry provides valued education in all aspects of light-based technology. I call this “light for health.” Since the inception of the Academy of Laser Dentistry in 1993, our organization has been the breeding ground for light-based dental technology and education. Yes, our members include notable researchers and educators. But, most importantly, the majority of our members are practicing dentists and hygienists who benefit from ongoing education and emerging technologies, being those who first-hand witness development in this field and then are properly educated to be competent clinicians.

The February 2007 issue of Contemporary Oral Hygiene states “...traditional dental diagnostics are inadequate and...jumping into treatment without a definitive diagnosis isn't in anyone's best interest.” Clinicians are questioning their reliance on hand instruments, like the explorer and the unaided eye, to detect disease. Even the dental radiograph has its limitations. Dentistry must transition to the medical model of diagnosis which includes light-based diagnostic soft tissue examination and noninvasive hard and soft tissue imaging of disease processes and tissue changes. Beside treatment lasers, photobiomodulation (low-level laser therapy) for pain relief, reduced inflammation, and tissue regeneration will afford our patients treatment modalities based on science and research.

Caries is a disease process just like periodontal disease. They are both infections that must be diagnosed and treated at the earliest opportunity in a minimally invasive manner. Caries management by risk assessment (CAMBRA) is an emerging philosophy which includes specific guidelines to lead the clinician through early detection, risk assessment, and treatment planning that includes chemical therapy and conservative restorative work. It has become very clear that visual, tactile, and radiographic examination is not sufficient in the caries diagnostic process. Cavitation of the tooth surface is a late stage in the dental carries process. Initial recognition at this stage is no longer acceptable. Early recognition of carious lesions prior to cavitation will be possible by light-based Optical Coherence Tomography in the near future. This will enable us to detect the disease process at the time of early demineralization and to intervene with antibacterial and remineralizing chemical therapy way before cavitation occurs. Similarly, early diagnosis of periodontal disease and noninvasive “optical biopsy” of tissue will be possible. Light-based mucosal examination and oral lesion detection is made possible through the use of light. Early discovery of dysplasia and precancerous tissue changes can save lives!

In the past, clinicians who used lasers for soft tissue surgical treatments wondered why there was reduced pain and inflammation, along with more predictable regeneration of tissue. It seems likely that low-level laser action existed even during laser curettage and tissue ablation! Now we have emerging science and research showing that there are beneficial reactions to light on the cellular level. Photobiomodulation for pain relief, reduced inflammation, and tissue regeneration will likely afford our patients additional treatment modalities.

Through the use of biophotonics and biomedical optics, the basic unit of light, the photon, can be used in many new ways far beyond those of “surgical” treatment lasers. Absorption, scattering, and reflectance of light are important basic principles for all light-based diagnostic and treatment instruments. The Academy of Laser Dentistry is committed to setting the standards in light-based diagnostic and treatment technologies and to provide quality continuing education so that clinicians can demonstrate their learned competence to their patients. It is quite amazing that the Bible began with “Let there be light,” and today the
Academy of Laser Dentistry is the guiding light for dental health.

**AUTHOR BIOGRAPHY**

Dr. Craig Gimbel graduated from New York University College of Dentistry in 1977. He was a Principal Investigator for the first Erbium:YAG laser U.S. FDA human hard tissue clinical trials in 1993. He has been utilizing various wavelengths of lasers since 1991. He is the author of “Hard Tissue Laser Procedures,” *Dental Clinics of North America*, October 2000. Dr. Gimbel has completed Advanced Proficiency laser certification, and is a Fellow of the American College of Dentists, Academy of General Dentistry, American Society of Dentistry for Children, and Academy of Dentistry International. He has authored numerous articles and has lectured extensively on their clinical use and related practice management. In 2003, Dr. Gimbel was the recipient of ALD’s T.H. Maiman award for excellence in dental laser research. Presently he is working on the research and development of the Optical Coherence Tomography Diagnostic Imaging System. Dr. Gimbel is the 2007-08 president of the Academy of Laser Dentistry.

Disclosure: Dr. Gimbel is cofounder and Executive Vice President, Clinical Affairs for Lantis Laser, Inc. Lantis Laser owns the exclusive license for dental applications of Optical Coherence Tomography. Dr. Gimbel has stock in Lantis Laser.

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Laser Ablation of Dental Hard Tissue

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SYNOPSIS

Much of practical laser dentistry relies on heat generated from the interaction of specific wavelengths of light with one or more components of the tissue that is being “treated.” This educational article reviews several aspects of laser interactions with dental hard tissues.

ABSTRACT

This paper discusses ablation of dental hard tissue using pulsed lasers. It focuses particularly on the relevant tissue and laser parameters and some of the basic ablation processes that are likely to occur. The importance of interstitial water and its phase transitions is discussed in some detail along with the ablation processes that may or may not directly involve water. The interplay between tissue parameters and laser parameters in the outcome of the removal of dental hard tissue is discussed in detail.

INTRODUCTION

The development of more-sophisticated lasers over the past two decades makes their widespread dental applications quite likely in the next few years. Presently a number of laser systems are commercially available for this purpose, and, in the coming years, more and different lasers will enter the market. Some of the presently available lasers may have only limited applicability in the clinic and, at times, their operating parameters are not clearly specified by the suppliers and are consequently poorly known or understood by the clinical users.

A number of research institutions are presently engaged in developing laser applications in dentistry, and clinical applications are likely to become significant as the understanding of the underlying interaction processes matures and becomes more generally known and understood. This is certainly true for ablation of dental hard tissue with lasers where the proper choice of laser may make the difference between helping the clinical work or burdening it financially.

Lasers are finding applications in many fields of medicine from surgery to ophthalmology to dermatology and dentistry. However, the lasers that have proven to be useful for one application may be useless if not damaging for other applications. Thus understanding the interplay between tissue parameters, laser parameters, and desired outcome is essential for success. This paper addresses the small subfield of applications of lasers for the removal of dental hard tissue. It concentrates on the important parameters and the processes that are likely to contribute to ablation. This paper is based on current understanding of the processes involved and draws on work being carried out at many institutions to study the ablation of biological tissues.

ABLATION PROCESSES

Laser ablation of dental hard tissue relies on the optical, physical, and biological properties of the tissue as well as the operating parameters of the laser. Together, these parameters determine the specific interaction processes leading to tissue ablation. The following sections discuss the individual tissue and laser properties and the main ablation processes responsible for the ablation of dental hard tissue.

1. Optical Tissue Parameters

The optical tissue parameters of primary importance to laser ablation are the absorption and scattering coefficients of the tissue. Directly connected with absorption and scattering is the optical index of refraction. These parameters are generally wavelength dependent as shown in Figure 1. Around \( \lambda = 3 \) \( \mu \)m the dental hard tissue absorption is dominated by water and OH\(^-\) ions while between \( \lambda = 9 \) and \( 10 \) \( \mu \)m the PO\(_4^{3-}\) ion is the primary absorber. The CO\(_2^{2-}\) ion is identified in the figure for the sake of completeness only. This wavelength dependence is due to electronic or vibrational transitions in one or several of the tissue constituents. In the near-infrared these resonances typically involve vibrational molecular levels that can be strongly temperature dependent. The exact temperature dependence is related to how tightly the vibrating molecular...
constituents are bound; thus one would expect the tightly bound OH\textsuperscript{–} radical (a component of the apatite mineral), giving rise to absorption near 2.78 \(\mu\)m, to be less temperature sensitive than the more loosely bound oxygen in H\textsubscript{2}O (water) that accounts for the 2.94-\(\mu\)m absorption.

2. Physical Tissue Parameters
The physical tissue parameters of general concern for tissue ablation are the thermal conductivity, thermal diffusivity, thermal expansion, and heat capacity. In addition, other basic properties of the tissue such as porosity, hardness, homogeneity, etc., are also important.

Heating an object rapidly and locally generally leads to temporal and spatial redistribution of this heat over the entire object unless part of the deposited energy is ejected before heat diffusion\textsuperscript{a} sets in. The temperature redistribution occurs during a time period characterized by the diffusion or relaxation time, \(\tau_{rel} \approx x^2/4D\) where \(x\) is the distance over which the heat was deposited and \(D\) (\(\sim 5 \times 10^4 \text{ cm}^2/\text{s}\) for enamel) is the thermal diffusivity. This relaxation time describes the time during which the temperature in the heated region drops to half of its original value and is distributed over roughly twice the original volume. For heat deposition by a laser, \(x\) corresponds to the absorption depth \(d_a = 1/\alpha\), where \(\alpha\) is the absorption coefficient of the tissue. Thus, if two lasers are incident on a particular tissue and laser 1 deposits its pulsed energy over an absorption length of 10 \(\mu\)m while laser 2 deposits its energy over 1 \(\mu\)m, \(\tau_{rel}\) is 100 times shorter for laser 2 than for laser 1. Of course, complete relaxation to a uniform temperature takes much longer.

An essential requirement for the successful use of lasers for the ablation of dental hard tissue is set by the condition that the temperature rise in the pulp of the tooth must not exceed 5\(^\circ\)C; otherwise pulp damage may occur. Furthermore no other tissue or organs should be compromised by the laser irradiation of the tooth.

3. Laser Parameters
Dental hard tissues can be ablated with a variety of pulsed lasers [continuous wave (cw) lasers are not suitable for this purpose]. The proper choice of laser requires matching the laser wavelength, pulse duration, intensity (W/cm\(^2\)) or fluence (J/cm\(^2\)), and spot size to the tissue parameters listed above. In addition, the repetition rate of the pulsed-laser output must also be chosen in concert with the tissue parameters and the desired outcome of the procedure.

Lasers relevant for tissue ablation span a very large parameter space. Wavelengths can range from the deep ultraviolet (UV) (wavelength, \(\lambda \geq 193 \text{ nm}\)) to the infrared (IR) (\(\lambda \leq 11 \text{ \(\mu\)m}\)), pulse durations can range from 0.1 ps to \(\leq 1 \text{ ms}\), and single-pulse energies can be between a few microjoules and a good fraction of a joule. These lasers can be focused to spot sizes as small as a few microns or as large as a few millimeters. Repetition rates can range from single pulses to 100 MHz (= 10\textsuperscript{6} Hz). Any particular laser typically allows only a small subset of these parameters to be realized, and switching between different lasers is not usually an economically viable option. However, a judiciously chosen laser may fulfill the ablation requirements for a number of hard tissue ablation applications.

Finally, significant requirements for a viable laser for dental ablation applications are price, maintenance, ease of operation, and ease of applying the laser energy to the treatment area.

4. Laser Interaction with Dental Hard Tissue
Irradiating dental hard tissue with a pulsed laser will heat the tissue to a depth and temperature that depend on the absorption and scattering coefficients of the tissue at that specific laser wavelength, the laser pulse duration, the pulse energy and the spot size or, equivalently, the laser fluence (energy per surface area, J/cm\(^2\)). In most cases of interest to laser ablation of dental hard tissue, the absorption coefficient is much higher than the scattering coefficient and scattering can be neglected. This applies particularly to laser wavelengths in the vicinity of 3 \(\mu\)m and 10 \(\mu\)m. In this region the incident laser is absorbed according to Beer’s law\textsuperscript{b} and the highest temperature always occurs at or near the surface struck by the laser. (Scattering can change some aspects of the energy deposition but note the fact that the highest temperatures occur near the surface.) However, the temperature distribution inside the tissue depends not only on where the laser energy is absorbed but also on the laser pulse duration.

If the thermal relaxation time of the tissue is longer than the pulse duration (see Sec. 2 above), the tissue heating is determined solely by the laser intensity inside the tissue. In this case no significant heat diffusion into the tissue occurs during the laser pulse. The maximum tissue temperature increases with incident laser intensity (or fluence) until ejected material interferes with the laser beam before it strikes the unablated tissue.

A very different situation arises if the thermal relaxation time is

\textsuperscript{a} Note that the thermal relaxation time does not depend on whether the energy is deposited within a thin layer located either on the surface of the sample or deeper inside.

\textsuperscript{b} 1 ps = 1 picosecond = 10\textsuperscript{-12} s; 1 ms = 1 millisecond = 10\textsuperscript{-3} s.

\textsuperscript{c} The laser intensity drops off exponentially inside the tissue, \(I = I_a e^{-\alpha x}\), where \(I\) and \(I_a\) are the laser intensities inside the tissue and at its surface, \(\alpha\) is the absorption coefficient, and \(x\) is the distance from the tissue surface.

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Seka et al.
shorter than the laser pulse duration. In this case the energy deposited by the laser still follows Beer’s law but the heat energy diffuses deeper into the tissue during the laser pulse. Consequently, for a given incident laser fluence, the maximum surface temperature is lower and the tissue is heated to greater depths during the laser pulse than would be the case if the thermal relaxation time had been longer than the laser pulse. However, for very high absorption coefficients it may be advantageous to use heat diffusion during the laser pulse to heat a layer somewhat thicker than the absorption depth without necessarily losing ablation efficiency, i.e., material volume (or thickness) removed per unit fluence (J/cm²).

Once material is ejected during the laser pulse, the laser light may be scattered and/or absorbed by the ejecta, leading to useless heating of the ejecta. This can effectively shield the unablated target from the incident laser, entailing a concomitant loss of ablation efficiency. This shielding effect is expected to be less important for small spot sizes since the outflow of ejecta is more divergent, thus reducing the number of potential absorbers in the plume encountered by the incident laser.

At very high laser intensities, a plasma consisting of free electrons and ions may be formed in the ejected material or on the target surface that can partly or completely shield the underlying hard tissue from the laser. This property is exploited advantageously in short-pulse laser ablation with pulse durations between 10⁻¹³ and 10⁻¹¹ sec. This approach relies primarily on nonlinear absorption at high intensities that does not depend particularly on the tissue type. This approach is interesting but laser complexity, repetition rate requirements, and thermal management at high repetition rates are such that it was decided not to include this topic in this paper. Similarly, lasers with wavelengths below 350 nm are not discussed here as carcinogenic considerations make their applications problematic.

5. Physics of Tissue Ablation
Ablation of tissue using lasers generally involves some form of phase transition within the tissue. In the case of hard tissue ablation this phase transition frequently involves water. Phase transitions in water include such everyday observations as the transition of liquid water to water vapor. An illustration of some of the phase transitions in water is provided in Figure 2. The equilibrium between the liquid and vapor phase of water is called the binodal and stretches from the triple point to the critical point. The triple point (0.01° C and 6.1 mbar) the liquid, vapor, and solid phases of water are in equilibrium and cannot be distinguished from each other. At the critical point (220.64 bar and 374.15° C) the liquid and vapor phases of water are in equilibrium and are also indistinguishable. (The liquid phase of water exists only below the critical point.)

If water at ambient pressure is heated slowly from room temperature (point 1 in Figure 2) to its boiling point (point 2), it will, upon further heating, boil at 100º C until all of the water is completely turned into vapor. If the heating process is very rapid, the water can be superheated well beyond 100º C without vaporizing. However, superheated water can exist only at temperatures below that given by the liquid spinodal shown in Figure 2. At that point (point 3) the superheated water becomes unstable and spontaneously decomposes into liquid droplets and vapor at the equilibrium pressure without change in temperature (point 4 in Figure 2). The new equilibrium pressure can be ~ 100 times higher than the
ambient pressure, resulting in an explosive aspect of this phase transition. Creating such high pressures in this manner is more than twice as efficient as when the same pressure had been reached through slow heating. Explosive phase transitions are thus energetically efficient for reaching very high pressures capable of dislodging (ablating) surrounding solid material.

The explosive phase transition in water is illustrative of what can happen at high rates of heat input to tissue. Similar effects can occur in dental hard tissue as mineral phase changes occur at higher temperatures. At present there is no single accepted view of the detailed mechanisms responsible for ablation of dental hard tissue at various wavelengths of irradiation. However, some reasonable pictures summarized below have emerged over the past several years.

a. Er:YAG Laser Ablation

The pores of dental enamel and dentin in the mouth are filled with water among the mineral crystals, occupying about 12% by volume for enamel and 25% for dentin. The primary absorber for the Er:YAG laser is water. Water within dental enamel or dentin is directly heated by Er:YAG laser pulses with an absorption depth in dental enamel of ~ 12 µm (Figure 1) corresponding to a thermal relaxation time of \( \tau_{\text{rel}} \approx 70 \) µs. (Note that the absorption depth and thermal relaxation times increase significantly with temperature.) When laser pulses shorter than 70 µs are used, heat does not diffuse out of the absorption region during the laser pulse, thus setting the stage for rapid tissue heating and the possibility of an explosive phase transition of the water entailing the efficient removal of enamel or dentin without need to heat the tissue above ~ 300° C. However, the residual heat left in the tissue below the removed volume can rapidly desiccate that zone and lead to the stalling of the ablation process as has been observed and reported in the literature.\(^{20,28}\)

Covering the enamel surface with water significantly changes the ablation process. Er:YAG laser absorption in water is extremely strong (\( \alpha > 10^4 \) cm\(^{-1} \)). The rapid heating of the thin water layer by the laser can lead to an explosive water phase transition that removes the water in the irradiated zone within 1 or 2 µs. The underlying enamel layer, with water remaining in the larger pores and fissures, is then exposed to the laser light. The rapid heating of the water in these areas can then cause explosive tissue removal in the same way as outlined above.

This scenario is plausible and in accord with the observation of dental hard tissue ablation. However, more-detailed experimental and modeling work is required before this scenario is fully acceptable.

b. Er:YSGG or Er,Cr:YSGG Laser Ablation

At the Er:YSGG wavelength of 2.797 µm, or the Er,Cr:YSGG wavelength of 2.791 µm, the light is absorbed by both the water in the pores between the crystals and the OH– ion within the mineral crystal structure, with an absorption depth of ~ 25 µm (Figure 1). Although these wavelengths are to the side of the strongest part of the free water band, this band is broad and readily encompasses these lasers. The OH– ion is tightly bound within the mineral crystals of the hard tissue matrix; thus irradiation at this wavelength directly heats the mineral, as well as the interstitial water. However, the heat transfer from the mineral to the interstitial water is very fast (one to a few microseconds) because of the small dimensions (~ 1 to a few microns) involved. Thus the water again becomes the primary process by which the explosive hard tissue...
removal progresses; consequently, hydration of the tissue is important just as in the case for Er:YAG irradiation. Thus, the practical differences between Er:YAG, Er,Cr:YSGG, and Er:YSGG laser hard tissue ablation are not very significant.20,28

c. CO\textsubscript{2} Laser Ablation

There are several prominent CO\textsubscript{2} laser wavelengths with markedly different absorption in dental hard tissue (see Figure 1). The most common CO\textsubscript{2} laser line at 10.6 \textmu m (\(\alpha = 800 \text{ cm}^{-1}\), \(d_a \approx 12 \text{ \mu m}\), corresponding to \(\tau_{rel} \approx 70 \mu s\)) has an absorption coefficient equivalent to that of water at a wavelength of 2.94 \textmu m (Er:YAG). In contrast, the 9.6-\textmu m CO\textsubscript{2} line is much more strongly absorbed (\(\alpha = 8000 \text{ cm}^{-1}\), \(d_a \approx 1 \text{ \mu m}\), \(\tau_{rel} \approx 1 \mu s\)). For the 9.3-\textmu m line the absorption depth is slightly longer (\(d_a \approx 3 \text{ \mu m}\) and \(\tau_{rel} \approx 5 \mu s\)). This very strong absorption has several consequences: First it heats the tissue to very high temperatures by directly heating the mineral; the exact temperature and depth depend on the pulse duration relative to \(\tau_{rel}\). Provided that the pulse duration is less than 50 to 100 \mu s the tissue surface is easily heated to and beyond the melting point of enamel (~1200° C). At that point phase transitions in the dental hard tissue change the mineral composition and liberate gaseous constituents that can build up to very high pressures within the tissue and eject the molten surface layer. Water may still play some role in the CO\textsubscript{2} laser ablation process but the much thinner tissue layers directly heated by the CO\textsubscript{2} laser raise the peak temperatures more rapidly and to higher values than would apply to Er:YAG or Er,Cr:YSGG energy deposition. Thus phase transitions in the hard tissue are estimated to be of primary importance. This conjecture is supported by the molten surfaces observed after CO\textsubscript{2} laser ablation compared to the unmodified and much rougher surfaces observed after Er:YAG laser ablation.20

A significant difference between CO\textsubscript{2} and Er:YAG laser ablation is found in the absorption of laser light in the ejected tissue. That absorption becomes negligible at 2.94 \textmu m as water is transformed into vapor. Thus the plume of ejected material may scatter the Er:YAG radiation but it is not absorbed. In stark contrast, CO\textsubscript{2} laser light – being absorbed by the mineral constituent of the hard tissue – decreases only modestly as the outflowing ejecta diverge out of the path of the incident laser. Thus the CO\textsubscript{2} laser continues to heat the expanding plume, representing energy lost for tissue ablation and consequently reducing the ablation efficiency (tissue mass removed for a given laser pulse energy). Moreover, the plume may be heated sufficiently to actually produce an ionized plasma that can refract and ultimately reflect all laser light.

Lengthening the CO\textsubscript{2} laser pulses at the same pulse energy can mitigate the loss of laser light in the plume in two ways: the lower intensity can reduce the likelihood of plume heating to the point of plasma formation, and it can give the outflow of ejecta more time to diverge out of the beam. In addition, structuring the laser pulse to consist of more or less distinct individual pulses on the several-microsecond scale could lead to improved ablation efficiency because of effective tissue removal between pulses.24

Providing water on the dental hard tissue is not required for CO\textsubscript{2} laser ablation per se; however, as will be seen later, there are distinct advantages for using water to improve the quality of the unablated remaining hard tissue surface.

Figure 3: Polarized light images of incisions in dentin produced with an Er:YSGG laser using 300-ns pulses (a) without and (b) with water, and using 200-\mu s pulses (c) without and (d) with water. Thermal damage zones appear black. (Adapted from reference [45] with permission.)
d. UV Laser Ablation
In the near UV, absorption is dominated by various organic constituents of the dental hard tissues (proteins, collagen, bacteria, etc.) as well as dental composites. In addition, UV light is strongly scattered in the dental hard tissue, preventing deep penetration into the tissue.\textsuperscript{20-23} While the ablation mechanisms involved in the UV are not very well understood, various experiments have found significantly higher ablation rates and lower ablation thresholds for dental composites and bacteria-laden surface layers such as dental calculus or carious tissue when compared to sound enamel or dentin. The preferential ablation of these tissue components is a great asset for these lasers that emit between 350 and 420 nm with pulse durations between 5 and 200 ns.\textsuperscript{16,18,35-45} This selectivity is most pronounced below 430 nm. Above that limit, light propagation deeper into the tissue may become an issue.

EXPERIMENTAL OBSERVATIONS
1. Er:YAG and Er:YSGG Laser Ablation
As indicated in the preceding section, ablation with Er:YAG and Er,Cr:YSGG or Er:YSGG lasers stalls after a few laser pulses when operated without water perfusion (Figure 3). In addition, the remaining tissue, whether enamel or dentin, displays significant thermal damage zones [Figure 4(a)], and bonding of restorative dental composites is poor.\textsuperscript{9} With water perfusion and laser pulse durations of up to 30 \(\mu\)s at a fluence of \(\sim 10\) J/cm\(^2\), one obtains excellent tissue removal with minimum thermal damage [Figure 4(b)] in dentin and similarly for enamel. The importance of water perfusion is obvious in Figure 4. In addition, it was found that irradiation with Er:YAG or Er:YSGG laser pulses in excess of \(\sim 30\) to 40 \(\mu\)s leads to a much less desirable surface due to thermal damage to the collagen matrix of dentin.

2. CO\(_2\) Laser Ablation
Ablation of dental enamel and dentin by CO\(_2\) lasers with wavelengths between 9.3 \(\mu\)m and 10.6 \(\mu\)m has been studied extensively. At fluences below the ablation threshold and for pulse durations less than the thermal relaxation time, a surface layer of \(\sim 10\) \(\mu\)m can be melted and rapidly recrystallized without injury to the pulpal area.\textsuperscript{47-48} The recrystallized surface mineral has reduced carbonate content and has been shown to be more acid resistant.\textsuperscript{21,47,49} Above the ablation threshold, one observes a marked difference in the CO\(_2\) laser-treated area compared with that for Er:YAG irradiation (Figure 5). While essentially all CO\(_2\) laser wavelengths shown in Figure 1 are suitable for ablation, the higher absorption coefficients of the 9-\(\mu\)m lines make them preferable.

While water perfusion is not essential for CO\(_2\) laser ablation, it has been found that without water, molten debris resettles on the tooth surface. This can interfere with subsequent laser pulses but it also leads to an undesirable surface.\textsuperscript{19} Adding water spray (or a thin water layer) eliminates this redeposition probably by the action of the rapid water inflow in between laser pulses. CO\(_2\) laser ablation rates and efficiencies have been measured at most CO\(_2\) laser wavelengths and several pulse durations and fluences. Optimal pulse durations are in the vicinity of the thermal relaxation times, i.e., below 100 \(\mu\)s for 10.6 \(\mu\)m and much shorter for the other CO\(_2\) lines. Most commer-
Cylindrical CO₂ lasers tend to emit pulses that contain a short (< 1 µs) pulse followed by a tail of several microseconds whose duration is determined by the laser gas composition, i.e., the exact mixture of CO₂, N₂, H₂, and He. These pulses ablate thin layers of ~ 1 µm per pulse before the intensity reaches levels at which the unablated tissue is shielded by the plume, most likely due to plasma formation.

CO₂ lasers at 9.3 µm with longer pulse durations (15 and 18 µs) as well as higher repetition rates (up to 500 Hz) have recently become available commercially. The observed single-pulse ablation rates were significantly enhanced over the standard (< 1 µs) pulses used previously.†50-55 These pulse durations are considerably longer than the thermal relaxation time (see Figure 1). This raises the question of how deep the laser-heated layer is. In the absence of ablation, thermal diffusion during the laser pulse would heat a layer of ~ 6 µm. During ablation, material is removed from the tissue, permitting deeper penetration of the laser light. This is only possible, however, if a significant part of the ejected material actually moves outside the laser beam due to divergent flow. (The heated ejecta continue to absorb the laser light.) Longer laser pulses and smaller beam spots are therefore preferable. However, the maximum pulse duration is limited by the depth heated by thermal diffusion and the minimum temperature required for ablation.

Improved drilling of dental enamel⁹ (Figure 6) was obtained with a "stretched" CO₂ laser at 10.6 µm. (The stretching refers to lengthening of the overall laser pulse duration whereby part of the energy contained in the initial intensity spike is transferred to lengthened tails as shown in Figure 6.) At ~ 10 J/cm² a 30-µm tissue column was removed by the laser. The observed constant removal rate (~ 30 µm/pulse) for fluences above 10 J/cm² indicates very efficient shielding of the tissue by the plume, as might be expected from the formation of a plasma of critical electron density that totally reflects all incident light. Clearly there is no advantage in applying more than 10 J/cm² for ablating enamel with this laser.

3. UV Laser Ablation
Among the most interesting aspects of UV ablation of dental hard tissue is its tissue specificity. This is clearly demonstrated¹⁸,³⁷,⁴⁴ by the

Figure 6: Drilling of submillimeter holes in a thin dental enamel section (a) using a stretched (blue) CO₂ laser pulse compared to the conventional CO₂ laser pulse shown in red (b). The ablation rate per pulse and ablation efficiency are shown in (c) as a function of the fluence (energy/area, J/cm²) on the tissue. ((b) and (c) are adapted from reference [19] with permission.)

Figure 7: Ablation thresholds for sound and carious dentin at 380 nm (200-ns pulse duration). The selectivity is excellent below ~ 1.8 J/cm² as determined from acoustic signals emitted at the onset of ablation. (From reference [39] with permission.)
ablation threshold shown in Figure 7. The UV absorption is understood to be due to the organic constituents of the tissue but it is not known which one. An intriguing application of this selectivity has been demonstrated in the removal of dental calculus. At fluences of ~ 1.5 J/cm², calculus is removed efficiently while the underlying enamel, dentin, or cementum remains unharmed (Figure 8). Similarly it is possible to selectively remove carious tissue without damaging the underlying enamel or dentin.²⁵

The selectivity has been shown to extend from a wavelength of ~ 320 nm¹⁷,²⁸,⁵³ up to ~ 420 nm. A similar selectivity has been found between ablation of dental composites and enamel as well as dentin (Figure 9). It is thus possible to efficiently remove composite and sealant¹⁷ including in the area of pits and fissures. A typical result is shown in Figure 9. A raster scan was used to ablate the carious tissue as well as the sealant.

**DISCUSSION**

Laser ablation of dental hard tissue involves an intricate interplay between the physical tissue parameters such as optical and thermal properties, elasticity, hardness, porosity, etc., along with the relevant laser parameters such as wavelength, fluence, and pulse duration. Of particular importance is the thermal relaxation time of the tissue, the absorption depth at the wavelength of the laser, and the laser pulse duration. If the thermal relaxation time corresponding to the absorption depth is longer than the laser pulse duration, it is possible to remove hard tissue efficiently while simultaneously removing most (or at least a large part) of the deposited laser energy. This is of great interest for protecting the pulp from excessive heating.

Water has been shown to be a significant contributor to efficient laser ablation of dental hard tissue even if it is only a relatively small constituent of the overall tissue. Phase transition, particularly the explosive phase transition of superheated liquid water, is particularly efficient in this context for Er:YAG, Er,Cr:YSGG, and Er:YSGG lasers. This phase transition has also proven beneficial to produce a clean tissue surface after CO₂ laser ablation.

Irradiating dental hard tissue with laser pulses with wavelengths that are strongly absorbed either by the mineral, the water, or any of its organic constituents can lead to very efficient and desirable ablation of the tissue. In many cases the actual ablation process involves interstitial water that is directly or indirectly heated by the laser during a very short time interval. This can lead to an explosive phase transition in the water that then removes surrounding layers of hard tissue with a minimum of absorbed laser energy. Phase transition in the mineral matrix can play a similar role at much higher temperatures such as those resulting during CO₂ laser ablation.

Ablation of dental hard tissues by CO₂ laser irradiation appears to be more finely controllable due to the

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**Figure 8:** Scanning electron microscope (SEM) image and a corresponding light microscope image of a molar with areas where calculus was selectively removed using a 400-nm laser. Black arrows indicate the regions of calculus removal. White arrows indicate corresponding areas in the two images. The SEM image clearly shows no ablation within the sound tissue underlying the removed calculus in either enamel or cementum.

**Figure 9:** Laser ablation of caries lesions and sealant in pits and fissures using a 355-nm laser of 3-ns pulse duration and a single-pulse fluence of 1.3 J/cm². (From reference [17] with permission.)
much higher absorption in the dental hard tissue as long as the laser pulse duration is chosen to be commensurate with the thermal relaxation time. In addition, the hard tissue is heated to higher temperatures than for Er:YAG or Er:Cr:YSGG lasers, resulting in fused mineral crystals near the surface of the treated area. The change in mineral content (reduction or removal of carbonate) also leads to a desirable higher acid resistance than is obtained for Er:YAG or Er:Cr:YSGG laser ablation.

Laser ablation of hard tissue in the near UV (350 to 420 nm) is of interest particularly for selective ablation of either curvaceous tissue or calculus removal. It is presently not entirely clear which of the tissue constituents is the primary absorber in this wavelength region although the organic constituents clearly play a major role. The uncertainty in the detailed absorption process also makes it difficult to pinpoint the ablation mechanism. However, here too, the water content appears to play an important role along with the change in physical parameters of the tissues at the interface between the sound tissue and the caries or calculus.

Recently Vila Verde et al. have used finite element analysis to model pre-ablation processes in dental hard tissue for irradiation near 3 µm and 10 µm. This model does not allow for phase transition but still gives reasonable estimates for optimum irradiation parameters consistent with the conclusions drawn here.

CONCLUSIONS
An analysis of ablation processes involved in the removal of dental hard tissue with lasers shows that phase transitions in the tissue are of primary importance. On the other hand, the intricate interplay between physical tissue parameters and laser parameters largely determines the quality and control of the ablation process, features that are clearly important clinically. Thus the wavelength of the laser, the absorption coefficient of the tissue at that wavelength, the laser pulse duration, and laser fluence are the prime parameters that determine the efficiency and control of the ablation process. An associated parameter, the thermal relaxation time, together with the effective absorption coefficient and its value relative to the laser pulse duration is a good indicator for the type of ablation control and efficiency that a particular laser can provide in practice. The mechanisms, parameters, and observations described in this article form the basis for producing lasers with improved efficiency and efficacy of ablation in the future.

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Disclosure: Dr. Seka is a full-time employee of the Laboratory for Laser Energetics, University of Rochester. He is also a member of the Scientific Advisory Board of and consultant to Xenogen, an Alameda, California biomedical company. Furthermore, he is a consultant to Lares Research, a Chico, California company involved in the manufacture of dental drills and dental lasers.

PERMISSIONS

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The Effect of Tip Wear on Er:YAG Laser Ablation Efficiency
Wayne J. Selting, DDS, Colorado Springs, Colorado

SYNOPSIS
Er:YAG laser tip wear has a marked effect on the efficiency of ablation. This article describes an important study that highlights the problems of tip wear, especially when ablating dentin, and provides practical information for use clinically.

INTRODUCTION
The ablation of enamel and dentin by the Er:YAG laser occurs through the explosive removal of tissue. Laser energy at 2940 nm is very highly absorbed by water. When it strikes an enamel or dentin surface, it penetrates and vaporizes water within the tissue causing explosive ejection of mineral particles.

Tissue ablation relies on the coherent delivery of laser energy. Laser tips provide reliable output as long as the emitting surface is clean, optically flat, and transparent. Tip wear creates a chipped, rough surface, significantly affecting energy transmission.

The goals of this study were to determine the cause of tip wear, the effect of tip degradation on ablation efficiency, and the efficacy of repolishing quartz tips.

METHODS AND MATERIALS
This study was conducted using an Er:YAG laser (DELight, Hoya ConBio, Fremont, Calif.) with an 80-degree quartz tip. Energy parameters of 25 pulses per second at 240 millijoules per pulse with water and air spray were used for all studies. The water flow rate was 8 ml/min. The tip was held perpendicular to the tooth surface at a distance varying between contact and 1 millimeter.

Twenty recently extracted, unerupted third molars were subjected to enamel ablation for 2 minutes on the facial or lingual surfaces. Dentin root surfaces were ablated in a similar manner. Teeth were weighed before and after ablation and weight loss was determined.

A new quartz tip was used for 20 minutes of enamel or dentin ablation (10 consecutive 2-minute ablations) to determine ablation efficiency deterioration. No attempts were made to improve the tip between ablations.

In a subsequent study to determine the efficacy of tip repolishing, the quartz tip was polished after each 2-minute ablation. Polishing was accomplished with either a fine diamond disc, a fine or superfine polishing disc (Sof-Lex™, 3M, St. Paul, Minn.) or a porcelain polishing wheel using light pressure for 5 seconds.

A monocular inspection microscope was used to study the laser tip. A digital camera was mounted in place of the eyepiece lens and attached directly to a laptop computer, producing an effective magnification of up to 225 power.

ABSTRACT
Laser tip wear can decrease light transmission and ablation rate. Quartz tips for the Er:YAG laser deteriorate rapidly when ablating dentin at high energy levels as a direct result of high velocity bombardment by calcified debris. Aggressive contact with the tooth surface during ablation can also cause significant tip damage.

While enamel ablation has little effect on tip efficiency when care is exercised, dentin ablation has a significant effect. Efficiency can be reduced by up to 60 percent after only 20 minutes of use under typical conditions.

Polishing quartz tips after every use maintains ablation efficiency. Polishing with rigid or coarse materials can cause internal fractures destroying the tip. Polishing for 5 seconds with a Sof-Lex™ Superfine disc or equivalent rehabilitates the tip emitting surface while removing minimal material and thus extends the useful life of the quartz tip.

Figure 1: New quartz tip.
Figure 2: Quartz tip after extensive clinical use.
RESULTS

Figure 1 shows a new quartz tip as supplied by the manufacturer. Figure 2 shows a tip after extensive clinical use on enamel, dentin, and composite resin restorations in routine patient treatment. Deterioration is evident and ablation efficiency is greatly reduced. Under controlled laboratory conditions, a more detailed understanding of tip damage emerges.

Figure 3 shows a tip after 30,000 laser pulses directed at an enamel surface. The tip-to-tooth distance was maintained between contact and one millimeter. The tip surface is pitted but damage is minimal. Ablation of dentin produces a dramatically different result. Figure 4 shows a tip after only 3,000 pulses directed at a dentin surface. There is significantly more damage than seen when ablating enamel for 10 times as long (Figure 2) under the same conditions. Figure 5 shows that very extensive damage occurs after 30,000 pulses.

Figure 6 shows a brand-new tip after preparing two occlusal-lingual fissures on teeth #14 and 15 on a clinical patient. A normal technique of lightly touching the tooth to stay within one millimeter of the surface was used. Preparation took approximately three minutes or about 4,500 laser pulses.

The damage consists of large peripheral chips caused by direct contact with a jagged, ablated enamel surface. This picture points out the importance of careful use and minimal surface contact. While it is important to stay in close proximity to the surface, repeated contact is detrimental.

Graph 1 shows that enamel ablation efficiency is nearly unaffected by tip use. After 20 minutes or 30,000 pulses, efficiency was virtually unchanged.

Dentin ablation, as seen in Graph 2, has a significant effect on ablation efficiency. After 10 minutes or 15,000 pulses, ablation efficiency had decreased by more than 40 percent. After 30,000 pulses ablation efficiency had decreased by 60 percent.

Repolishing quartz tips was shown to be effective when an appropriate technique was used. Graph 3 shows that efficiency can be maintained at an acceptable level with constant repolishing. Simply polishing with a Sof-Lex™ superfine disc for 5 seconds as shown in Figure 7 can maintain efficiency without wearing away excessive quartz. Using this technique, a tip may be repolished as many as 100 times before needing to be replaced.

Polishing with a fine Sof-Lex™ disc for five seconds maintains efficiency but wears away significant amounts of the quartz tip, drastically shortening its useful lifespan. Polishing with a porcelain wheel does not provide enough abrasion to remove surface defects and quartz tip efficiency steadily declines.
Graph 4 illustrates the value of continuous polishing. After a quartz tip was used for 20 minutes to ablate dentin, it lost about 60 percent of ablation efficiency. It was polished for 5 seconds and regained almost all of its original efficiency. After an additional 10 minutes of use it had again lost more than 30 percent of its efficiency. Polishing once more returned it to high efficiency. It will be noted that each polishing returns the tip to a slightly lower level of ablation efficiency. Polishing only after extended periods of use (10 to 20 minutes) leaves the surface deeply pitted and requires longer polishing or use of a stronger abrasive. As shown in Graph 3, this is not an issue when polishing every 2 minutes or after every use.

Using a coarse, inflexible polishing medium such as a Joe Dandy disc, fine emery, or fine diamond disc is ill-advised. A 5-second polish with a fine diamond disc, as seen in Figure 8, caused internal fractures destroying the tip permanently. Dentin ablation was reduced by 80 percent and could not be corrected.

**DISCUSSION**

To assume that coherent laser light could pass through a chipped and pitted quartz tip efficiently is wishful thinking. As shown very clearly in the present study, tips deteriorate rapidly with use when ablating dentin. Although the mechanism is not known for sure, it appears that the rapid deterioration of quartz tips when ablating dentin at high energy levels is a direct result of high velocity bombardment by calcified debris. Dentin has a high water content and a high protein content compared to enamel, apparently making it easier for ablated particles to damage the tip than during enamel ablation. Aggressive contact with the tooth surface (including jagged enamel) during ablation can also cause significant tip damage.

Scattered laser light will strike many areas of the tooth at energy densities below the ablation threshold. This energy is absorbed, heating and dehydrating the enamel or dentin. Ultimately, this can compromise pulp vitality and, through dehydration, decrease the ability of subsequent laser pulses to ablate.

While studies have repeatedly shown that there is minimal change in pulpal temperature when ablation is carried out with water coolant present, subablative heating should be considered a potential problem and avoided where possible.

The emitting surface can be damaged by direct mechanical impact. Even light contact during routine use can rapidly damage the tip surface. While it is important to stay within about one millimeter of the tooth surface for efficient ablation, direct contact should be avoided.

Polishing quartz tips after every single use should be considered part of routine protocol. Gentle technique with just enough pressure to slightly deform the flexible disc should be used when polishing.

Energy parameters were kept the same for both enamel and dentin ablation to provide a measure of direct comparison of ablation rate. These settings also mimic a routine scenario. When
ablating through enamel, some time will be spent ablating a combination of dentin and enamel before switching to a lower dentin setting. In cases where the patient is anesthetized and sensitivity is not a concern, some dentists complete the entire preparation at the higher, more efficient, energy setting.

CONCLUSION
Quartz tips for the Er:YAG laser deteriorate rapidly when ablating dentin at high energy levels and can significantly affect ablation efficiency. Deterioration is a direct result of high velocity bombardment by calcified debris. Aggressive contact with the tooth surface during ablation can also cause significant tip damage.

While enamel ablation has little effect on tip efficiency when care is exercised, dentin ablation decreases efficiency significantly. Efficiency can be reduced by up to 60 percent after only 20 teeth are prepared under typical conditions. Polishing quartz tips after every use maintains ablation efficiency. Polishing with rigid or coarse materials can cause internal fractures, destroying the tip. Polishing for 5 seconds with a Sof-Lex™ superfine disc or equivalent provides the best result. This mild abrasive rehabilitates the tip emitting surface while removing minimal material and, thus, extending the useful life of the quartz tip.

AUTHOR BIOGRAPHY
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Disclosure: Dr. Selting has no commercial affiliations or relationships.

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The Use of Laser Energy for Therapeutic Ablation of Intraoral Hard Tissues

Position Paper: Science and Research Committee, Academy of Laser Dentistry

Adopted March 2007

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SYNOPSIS
The present use of lasers in dentistry for the ablation of hard tissues is summarized in this publication together with a brief statement of scientific rationale.

EDITOR’S NOTE
This is the first of a series of position papers on various uses of lasers in dentistry, developed by the Science and Research Committee of the Academy of Laser Dentistry (ALD). This position paper was approved by the ALD Board of Directors in March 2007. The paper is not designed as a comprehensive literature review or as a detailed historical document. It covers aspects of the ablation of hard tissues relevant to dentistry, utilizing lasers currently available. The document will be revised and updated as technology changes and improves. It will require several other such papers to describe other applications. The reader is referred initially to the bulleted summary that highlights the key points of the paper, and then to the body of the text for supporting details.

SUMMARY
- When the wavelength of incident laser light is matched to the absorption band(s) of a target tissue component, light energy is converted primarily to heat which causes tissue change and/or ablation.
- To be therapeutically effective and efficient, it is necessary to deliver light of sufficient energy over time to effect tissue change, without causing unwanted collateral thermal damage by conduction of excess heat into the surrounding tissues.
- Neodymium YAG (Nd:YAG, 1064 nm). While published studies have indicated some safe and effective usage, the clinical significance of the Nd:YAG laser wavelength was shown to be of only marginal benefit to the restorative dentist because of its very low absorption in hard tissues.
- Continuous wave (CW) carbon dioxide laser (CW CO₂, 10,600 nm). The commonly available continuous wave CO₂ laser showed poor interactions with enamel, with reports of charring, cracking, and damaging heat buildup within tooth and bone structure.
- Erbium YAG (Er:YAG, 2940 nm) and Erbium, Chromium YSGG (Er,Cr:YSGG, 2780 nm). The pulsed Er:YAG and Er,Cr:YSGG laser wavelengths are well absorbed by target hard tissue components, primarily water. These wavelengths offer safe use in cavity preparation.
- Both Er,Cr:YSGG and Er:YAG laser wavelengths are absorbed well in water, with the Er:YAG being somewhat more strongly absorbed in water than the Er,Cr:YSGG.
- The absorption in water is the primary absorption for these two wavelengths due to a relatively broad water band around 3,000 nm.
- In addition, there is a small absorption at around 2,800 nm by the hydroxyl group of the (carbonated) hydroxyapatite mineral of the tissues, but this is far outweighed by the water effects.
- Water is naturally present among the crystals in enamel, dentin, cementum, and bone deep into the tissue, filling every available pore. Enamel, dentin, bone, cementum, and carious tissue have, relatively, descending mineral density and ascending water composition.
- For both Er:YAG and Er,Cr:YSGG laser wavelengths, the laser energy is absorbed primarily by the water and is rapidly converted to heat, which causes superheating of the subsurface water, resulting in a disruptive expansion in the tissue.
- The currently marketed mid-infrared (IR) laser wavelength lasers (around...
3,000 nm) are free-running pulsed lasers. If the correct energy is used, application results in safe pulpal temperature rises of less than 5° C.

- Laser irradiation of enamel and dentin by Er:YAG or Er,Cr:YSGG lasers produces a “super-rough,” micro-cavitated surface.
- Studies have identified the fragility of laser-irradiated enamel, relative to the stability of the post-restoration margins. A combined approach of laser-irradiation and acid-etch techniques, to overcome such potential problems, is suggested. Regardless, there is the need to remove grossly overhanging and unsupported enamel to provide a stable post-restoration margin.
- The rate (speed) of ablation of dental hard tissue is a consequence of the amount of incident laser energy delivered to the tissue as well as the effects of wavelength, pulse duration, pulse shape, repetition rate, power density, the thermal relaxation time of the tissue, and delivery mode.
- Fluoridation of the tissue, incident angle of the delivery tip relative to the tooth, and presence of ablation products will affect the speed of ablation.
- The ablation threshold of human enamel has been reported to be in the range of 12-20 Joules/cm², and for dentin 8-14 Joules/cm² for the Er:YAG and Er,Cr:YSGG laser wavelengths, respectively.

- **Ablation of bone.** The development of Er:YAG and Er,Cr:YSGG lasers has enabled bone ablation to be carried out with minimal adjacent damage, and the use of erbium lasers in dentoalveolar surgery represents a less-traumatic experience for the patient.
- As with tooth tissue ablation, bone tissue cutting is a thermally induced explosive process and it is essential to maintain a coaxial water spray to prevent heat damage, which delays healing.
- Bone composition is very similar to dentin from the perspective of laser-tissue interactions. In maxillary alveolar bone, the speed of laser cutting is comparable with that of a bur, and slightly slower in the mandible.

**Future developments and applications.** Several exciting new possibilities for the use of lasers on hard tissues are likely to become available to the practicing dentist in the near future. Two such examples are:
- Selective ablation of calculus by wavelengths in the ultraviolet/blue region will offer less invasive dentistry.
- Low microsecond-pulsed carbon dioxide lasers with a 9.3- or 9.6-µm wavelength have great potential for efficient and effective ablation of sound and pathological hard tissues, as well as modification of the mineral to increase resistance to caries attack.

**INTRODUCTION**

Laser light is unique in being emitted as a monochromatic, coherent, and collimated beam of nonionizing electromagnetic (EM) energy which, for current dental purposes, spans the visible and infrared regions of the EM spectrum. Through a correct matching of incident laser wavelength with a target tissue element, light energy is converted primarily to heat, which causes tissue change or ablation.

For the present document the use of laser light for intraoral hard tissue ablation will be the treatment that is primarily discussed. Other uses and mechanisms are known, but these are not the topic of the present paper.

In order for any laser-tissue interaction to be therapeutically effective and efficient, it is necessary to deliver light energy of sufficient value over time to effect tissue change, without causing unwanted collateral thermal damage by conduction of excess heat into the surrounding tissues.

**LASER ENERGY AND DENTAL HARD TISSUES**

Healthy oral hard tissues include enamel, primary and secondary dentin, cementum and alveolar bone. For the purposes of the application of laser energy in restorative dental procedures, demineralized and carious hard tissue must also be considered.

In addition to the prime interaction of laser energy with these tissues, there also exists a need to establish a rate of interaction that is commensurate with a time frame that allows such interaction to be clinically acceptable, by limiting the time for conduction of excess energy to occur, while at the same time being fast enough to be clinically acceptable.

Early investigation into the use of lasers for the ablation or modification of dental hard tissue were carried out using a ruby laser (red, visible, 694.3 nm), a carbon dioxide continuous-wave laser (infrared, 10.6 µm), and subsequently the neodymium:YAG laser (infrared, 1064 nm). The latter, the Nd:YAG laser, was the first to be marketed for soft tissue laser dentistry in the USA and numerous investigations were done to investigate its utility for hard tissue use. Investigations included the ablation of (pigmented) diseased tissue, the antibacterial effect of this laser wavelength, and the possible effects on the vital dental pulp. While studies were published to establish some safe and effective usage, the clinical significance of this wavelength was shown to be of only...
marginal benefit to the restorative dentist, because of its very low absorption in sound enamel or dentin. High fluences are needed for ablation unless the region to be ablated is pigmented or a pigment is applied to the surface. Furthermore, several studies drew conclusions that the Nd:YAG wavelength could cause unwanted heating side effects, such as cracking and melting of composite mineral structures. Conversely, some workers published reports of the beneficial acid-resistance in enamel following exposure to low-power Nd:YAG energy and the resulting reconstitution of melted mineral in enamel. However, what is not commonly realized is that an absorbing material (e.g., black ink) must be applied first for this wavelength to effectively increase the acid resistance of dental enamel, due to the very low absorption of Nd:YAG in enamel and dentin.

Other early studies on enamel ablation used the other commonly available laser wavelength, carbon dioxide (10,600 nm), but this laser gave poor interactions, with reports of charring, cracking and damaging heat buildup within tooth and bone structure. The available carbon dioxide lasers at that time were continuous wave with no cooling water, which resulted in very high energy deposition in the hard tissue due to the combined absorption of this wavelength in both the mineral and in the water component. Excess heat was rapidly deposited with the continuous-wave mode rather than pulsed mode where there is time for the tissue to cool between pulses, and the energy density of the pulses can be better tailored to the needs. The continuous-wave CO₂ laser use resulted in reports of poor clinical benefit of this wavelength. The successful use of pulsed CO₂ lasers for ablation is expected to become a clinical reality in the near future.

The work of workers such as Keller and Hibst, among others, illustrated the potential of the Er:YAG (2.94-μm wavelength) for effective ablation of dental hard tissues. This led to the development and marketing of free-running, mid-infrared wavelength (around 3,000 nm) lasers during the mid-1990s. This was a real achievement in addressing laser wavelengths that were complementary to target tissue elements, and offered clinically significant ablation rates that did not cause pulpal or collateral thermal injury if the right energy levels were used. The erbium:YAG (2940 nm) and erbium, chromium:YSGG (2780 nm) laser wavelengths are well absorbed by target hard tissue elements and appeared to offer safe use in cavity preparation. ABLATION OF HARD DENTAL TISSUES BY MID-INFRARED LASERS

It may seem incongruous, but to any clinician who may wish to use a laser in restorative dentistry, the high-speed rotary drill is seen as the “gold standard.” Ease of use and speed are often accepted as plausible, even when several studies have shown that high-speed drilling gives rise to surface and pulpal temperature rise, tissue cracking, and unnecessary removal of healthy surrounding tissue during cavity preparation. Such incongruity is compounded by the number of papers attesting to the precision, low thermal rise, and selectivity of mid-infrared laser wavelengths when used on dental tissue. Generally, the only drawback would appear to be the lower “speed” of cutting, when compared to the drill.

Notwithstanding, the use of Er:YAG and Er,Cr:YSGG lasers in restorative dental procedures has progressed during the past 10 years, and within a given clinical setting the following factors will be significant in determining effective treatment outcomes:

- Target chromophores
- Mechanism of interaction
- Emission mode
- Pulse duration (pulsed or continuous wave, chopped)
- General thermal effects
- Relationship of laser action to cavity design and restoration retention
- Speed of “cutting”
- Power values.

a) Target chromophores

Both Er,Cr:YSGG and Er:YAG laser wavelengths are absorbed well in water, with the Er:YAG being somewhat more strongly absorbed in water than the Er,Cr:YSGG. This absorption is several orders of magnitude greater than seen with the Nd:YAG wavelength. The absorption in water is the primary absorption for these two wavelengths due to a relatively broad water band around 3,000 nm. This is water that is naturally present among the crystals in enamel, dentin, cementum, and bone deep into the tissue, filling every available pore. In carious tissue there is an even higher quantity of water that replaces the lost mineral. The key to understanding hard tissue ablation by these wavelengths is that it is primarily due to this absorption in water and superheating of the water below the surface (see below, and Figure 1). Enamel, dentin, bone, cementum and carious tissue have, relatively, descending mineral density and ascending water composition.

In addition, there is a small absorption at around 2,800 nm by the hydroxyl group of the (carbonated) hydroxyapatite mineral of the tissues, but this is far outweighed by the water effects. Unfortunately many publications about laser effects on hard tissues have perpetuated the erroneous statements that dental mineral strongly absorbs these wave-
lengths. Not only is this incorrect, but it misleads us in understanding the mechanism of how ablation occurs due to laser application at these wavelengths and misdirects the use of these laser wavelengths.

b) Mechanism of interaction
When incident laser energy directed onto hard dental tissue is absorbed by the prime chromophores, either water or carbonated hydroxyapatite, one of two effects occur. For both Er:YAG and Er,Cr:YSGG wavelengths this energy is absorbed primarily by the water and is rapidly converted to heat, which causes superheating and a phase transfer in the subsurface water, resulting in a disruptive expansion in the tissue. Through this mechanism, whole tissue fragments are ejected and a hole is cut in the tooth, with little or no alteration to the mineral itself.

If laser light is effectively absorbed by the mineral, the crystals themselves may be heated above their melting point and some disruption of the crystal structure occurs with subsequent resolidification in a different form, or direct ablation of the mineral, but there is also conductive heat transfer to interstitial free water. Relatively high fluences are needed at these wavelengths for this to occur.

c) Emission mode and pulse duration
The emission mode of currently marketed mid-infrared wavelength lasers is defined as free-running pulsed. Currently commercially available lasers emit a pulse train of 50-250 microsecond pulses on average which, when delivered in rates of 3-50 Hz (pulses per second) values, represent duty cycle values of approximately 80%. While pulse durations are close to the thermal relaxation times of enamel and dentin, it is evident that there exists a need to examine further ultrashort pulse durations – and associated high peak power values – in an attempt to create sufficient ablative force without inducing collateral thermal damage.

d) General thermal effects
The vital dental pulp is acutely sensitive to thermal change. Studies have established that rotary instrumentation can cause conductive thermal rise in excess of 20°C above 37.4°C. With regard to laser irradiation of dental tissue, the explosive defragmentation resulting from water-assisted mid-infrared laser wavelengths allows much of the heat to escape from the cavity carried in the ablated particles, resulting in pulpal thermal rises of less than 5°C. The affinity of mid-infrared laser wavelengths with water allows the main absorption to take place in demineralized tissue richer in organic material and with a higher percentage of water, thus protecting the sound underlying tissue with a reduced penetration of the beam. Contrary to this, the accumulation of ablation debris within a deep cavity can lead to “super-heating” which can lead to conductive heat damage.

e) Relationship of laser action to cavity design and restoration retention
The emergence of conservative restorative cavity design, at variance with the classical “G.V. Black” model, represents a move toward minimal intervention with the development of acid-etch retention of composite resins restoratives. Laser irradiation of enamel and dentin by Er:YAG or Er,Cr:YSGG
laser results in a “super-rough,” micro-cavitated surface that may predispose to ideal retention of composite resin. A succession of studies has identified the fragility of laser-irradiated enamel, relative to the stability of the post-restoration margins. Studies have proposed a combined approach of laser-irradiation and acid-etch techniques to overcome such potential problems. Irrespective, there may well remain the need to remove grossly overhanging and unsupported enamel with a rotary bur, in order to either expedite cavity preparation or provide a stable post-restoration margin. Such consideration places patient care above the ideology of “pure” laser dentistry.

Furthermore, mention should be made as to the suitability of current lasers in the provision of full-veneer crowns. With regard to the preparation of single-surface veneers, using either direct or indirect materials, there is acceptance of the benefits that laser techniques may bring. Conversely, the use of lasers alone in the preparation of full-coverage indirect restorations is to be deprecated, due to the time required, the very large total energy input that would be required, and the possible irreversible damage to the pulp.

f) Speed of “cutting” as related to laser parameters
The rate (speed) of ablation of dental hard tissue is a consequence of the amount of incident laser energy delivered to the tissue as well as the effects of wavelength, pulse duration, pulse shape, repetition rate, power density, the thermal relaxation time of the tissue, and emission mode. In addition, it is necessary to avoid the possibility of heat buildup in the tissue (and undesirable heat conduction to the pulp) and also to prevent the accumulation of products of ablation, or char.

Mid-infrared ablation of dental hard tissue has given rise to the concept of the existence of two wave fronts of interaction – an ablation front and a thermal front. It is important that the ablation front should always precede the thermal front, if the possibility of damaging heat rise is to be avoided. Studies, therefore, have looked at the effects of too much incident power and the buildup of ablation products, or their removal by means of a coaxial water spray.

It is also evident that the desire to match cutting speeds with those of rotary instruments has led to power delivery far in excess of that postulated by Keller and Hibst, relative to the ablation threshold of enamel. Coexistent with such power levels and heat conversion, studies have been carried out to determine the effect of reducing the pulse duration of the laser energy. It has been shown that by reducing the pulse duration, peak power values rise, ablation is more efficient, and heat transfer is minimized.

In addition to the above, other factors such as fluoridation of the tissue, incident angle of the delivery tip relative to the tooth, and presence of ablation products will all affect the speed of ablation. Several reports have shown the effectiveness of addressing the delivery tip parallel to the axis of the enamel prisms in order to access the inter-prismatic, higher-water content structure.

Generally, the rate of tissue ablation with a laser, when compared to a high-speed rotary instrument, has given rise to claims of 80% slower in enamel, and comparable speed in dentin, when matched against a slow-speed drill. In addition, the use of sharp curettes in removing gross caries can allow lasers to be used within an acceptable time frame.

The debate over what constitutes a “recommended” power value for laser-assisted ablation of dental hard tissue is compromised by many conflicting factors, not least the danger of the anecdote. The ablation threshold of human enamel has been reported to be in the range of 12-20 J/cm², and for dentin, 8-14 J/cm² for the Er:YAG and Er,Cr:YSGG laser wavelengths respectively. For an average laser delivery spot size, with the use of a free-running pulsed emission mode, this may equate to approximately 150-250 mJ/pulse. What is of paramount concern is the delivery of sufficient laser energy, within a minimal time, to achieve clinically acceptable ablation rates without causing adjacent tissue damage. Apart from those studies that have determined minimal levels of power necessary, there does seem to be a plethora of anecdotal reports. It would seem prudent for the clinician to follow the manufacturer’s guidelines in establishing laser treatment protocols for a given laser, bearing in mind the differing operating parameters of air, water, spot size, and any power losses that may occur within differing delivery systems.

g) Bone ablation
Clinical procedures that may involve the cutting or ablation of bone include surgical extraction, periodontal surgery and infrabony pockets, clinical crown lengthening, and apicectomy. The development of Er:YAG and Er,Cr:YSGG wavelengths has enabled bone ablation to be carried out with minimal adjacent damage, and the use of erbium lasers in dentoalveolar surgery represents a less-traumatic experience for the patient when compared to the intense vibration of the slow-speed surgical bur. As with tooth tissue ablation, tissue cutting is a thermally induced explosive process and it is essential to maintain a coaxial water spray to prevent heat damage which would delay healing. Bone composition is very similar to dentin from the perspective of laser-tissue interactions. The
mineral is similar, the protein content is similar, as is the water content.

In maxillary alveolar bone, the speed of laser cutting is comparable with that of a bur and slightly slower in the mandible, reflecting the greater mineral density of cortical bone. It is considered important that excessive power parameters be avoided to reduce the “stall-out” effect of debris and minimize blood spatter. Laser parameters of 350-500 mJ, 10-20 Hz (average power range 3.5-7.0 Watts) with maximal water spray appear to effect good ablation rates.

Studies into the healing of laser-ablated bone support the contention that the reduction in effects such as physical trauma, tissue heating, and bacterial contamination may lead to uncomplicated healing processes, when compared to conventional use of a surgical bur. The microanalysis of the surface of bone that has been ablated using lasers shows little evidence of thermal damage, and any char layer appears to be restricted to a minimal zone of 20-30 µm in depth.

### FUTURE DEVELOPMENTS

There are several exciting new possibilities for the use of lasers on hard tissues that are likely to become available to the practicing dentist in the near future. A couple of examples are presented here. In each area years of research have set the stage for the development of commercially viable lasers.

Selective ablation of calculus by wavelengths in the ultraviolet/blue region is one example. Ablation of carious enamel, dentin, and cementum, as well as bone may be more efficiently done with wavelengths not currently available commercially. The strongest absorption bands for the carbonated hydroxyapatite mineral of teeth and bone are in the 9.3 - 10.6-µm wavelength region, with 9.6 µm being the strongest. Pulsed carbon dioxide lasers have great potential for ablation and modification of mineral to increase caries resistance.

Recent studies have shown that by matching the pulse duration to the thermal relaxation time of the tissue and optimizing the fluence per pulse, very efficient ablation of enamel, dentin, and carious tissue can be achieved with little peripheral damage. Low microsecond pulse-duration lasers (e.g., 5-10 µs) of 9.3- or 9.6-µm wavelength have great potential. Furthermore laboratory studies have shown that similar irradiation conditions, but at lower fluences, can beneficially alter the mineral of enamel to make it more resistant to acid and consequently to inhibit caries progression. Clinical studies will be needed to confirm the viability of this methodology in the mouth. It will be possible to produce lasers that can ablate dental hard tissues and bone, while at the same time inhibiting subsequent caries progression, and keeping peripheral damage to a minimum.

### SAFETY CONSIDERATIONS

All laser-tissue interaction using surgical lasers carries general and specific safety concerns. With regard to the statutory instruments ANSI 136.1 (2007) and IEC 60825-1/A2:2001, suitable precautions to protect intraoral nontarget tissue and patient and operator’s eyes and skin should be employed.

### AUTHOR BIOGRAPHY

Dr. Steven Parker studied dentistry at University College Hospital Medical School, University of London, UK and graduated in 1974. He is in Private Practice in Harrogate, UK. He holds Fellowship and Diplomate status with the International Congress of Oral Implantologists. Dr. Parker has been involved in the use of lasers in dentistry since 1990. Prior to joining the Academy of Laser Dentistry in 1993, he was President of the British Dental Laser Association. He joined the Board of Directors of the Academy in 1996 and became chair of the International Relations Committee. From 1999 through 2004, he was chair of the Committee for Proficiency Recognition and co-editor of Wavelengths, the former journal of the Academy of Laser Dentistry. He was awarded the Leon Goldman award for Excellence in Clinical Laser Dentistry by the Academy in 1998. In addition, Dr. Parker holds Advanced Proficiency status in multiple laser wavelengths and completed the Academy Educator Course at the University of California – San Francisco in 2000. He is an ALD- Recognized Standard Proficiency Course Provider. He has held consultancies with multiple laser companies and has presented courses, lectures, and workshops worldwide. He has authored numerous articles on the use of lasers in dentistry, including a chapter “The Use of Lasers in Fixed Prosthodontics” in the October 2004 Dental Clinics of North America. Dr. Parker was the 2005 President of the Academy of Laser Dentistry. Dr. Parker may be contacted by e-mail at thewholetooth@easynet.co.uk.

**Disclosure:** Dr. Parker has no current affiliations with any company.

### REFERENCES


The following cases were presented by four recent Advanced Proficiency candidates during the Academy of Laser Dentistry annual conferences in New Orleans and Tucson.

1. Dr. Alberto Trigas Damian utilizes an Er:YAG laser for removal of carious lesions in 13 maxillary and mandibular teeth. The wavelength’s ability to ablate the compromised dentin is demonstrated, allowing multiple restorations to be placed during the same appointment.

2. Dr. Raminta Mastis treats a periodontally diseased furcation area on a lower molar, using the Er:YAG laser for a soft tissue incision and granulation tissue removal. The shallow depth of penetration of this wavelength allows the debridement to remove thin layers of tissue, preserving as much healthy periodontium as possible.

3. Dr. Giovanni Olivi utilizes an Er,Cr:YSGG laser to revise a lower anterior frenum and for gingivoplasty of the surrounding soft tissue. Similar to the Er:YAG’s ability to remove thin layers of tissue at a time, this laser is ideally suited for contouring gingival tissue.

4. Dr. Alfred Wyatt performs closed flap osseous and gingival crown lengthening for access to a carious lesion on a maxillary molar, using an Er:YAG laser. This case emphasizes the fact that this wavelength is ideally suited for bone removal as well as for gingival surgery, targeting the water of both of those tissues.

These cases demonstrate various clinical applications of the erbium family of laser wavelengths, and show how, by employing proper parameters and techniques, the treatment objectives can result in successful outcomes.
Thirteen Class V Restorations Prepared with an Er:YAG Laser

Alberto Trigas Damian, DDS, Carballino, Ourense, Spain


SYNOPSIS

An Er:YAG laser was used for removal of carious lesions in thirteen maxillary and mandibular teeth, allowing multiple restorations to be placed during the same appointment.

PRETREATMENT

A. Outline of Case

1. Clinical Examination

A 58-year-old female patient presented with unbearable sensitivity to cold and heat in spite of desensitizing treatments. She presented with abrasions in the cervical region of 16 teeth (three were asymptomatic). She did not present with any alterations of the TMJ and the occlusion was Angle's classification Class I. The patient's medical history revealed no medical abnormalities or predisposing risk factors.

2. Radiographic Examination

A panoramic X-ray was taken. The alveolar bones presented normal trabecular pattern and no other alteration of importance was visualized (Figure 1).

3. Soft Tissue Status

The gingival pockets had healthy probing depths of no greater than 3 mm, with no inflammation or bleeding. The oral soft tissues appeared healthy with no apparent pathology.

4. Hard Tissues Status

The patient presented cervical abrasions with great sensibility in teeth #3, 5, 8, 9, 10, 11, 12, 14, 19, 20, 28, 29 and 30 (Figures 2, 3, 4, 5, and 6) and asymptomatic cervical abrasions in teeth #23, 24, and 25 (Figure 7). The teeth were hypersensitive to thermal stimulation, but were vital.

5. Other Tests

Percussion tests were normal. Examination revealed that the patient had worn incisal edges, especially of the cuspids, and her lateral occlusion exhibited group function instead of cuspid protected rise.

B. Diagnosis and Treatment Plan

1. Provisional Diagnosis

Dentinal hypersensitivity.

2. Final Diagnosis

Dentinal hyperesthesia due to cervical abrasions caused by excessive tooth brushing, bruxism, and subsequent excessive lateral excursive forces.

3. Treatment Plan Outline

Preparation of 13 class V restorations with an Er:YAG laser. An anti-bruxism appliance is to be fabricated at a later date. The asymptomatic teeth were not treated.

Figure 1: Preoperative panoramic film

Figure 2: Preoperative view of the maxillary right quadrant, showing abrasion lesions

Figure 3: Preoperative view of the maxillary anterior sextant

Figure 4: Preoperative view of the mandibular right quadrant, showing abrasion lesions
4. **Indications**
The abrasion areas need definitive restorations, since desensitizing treatments had failed to alleviate the pain.

The Er:YAG laser is indicated for the tooth preparation, since it can easily prepare dentin and enamel.

5. **Contraindications**
There is no contraindication for the restorative treatment; however, the successful retention of the restorations could depend on the patient’s occlusal habits.

No contraindications were considered for laser treatment.

6. **Precautions**
Adequate water spray and lower power should be used for tooth preparation and conservation of healthy tooth structure.

7. **Treatment Alternatives**
Conventional preparations with dental handpieces are viable treatment alternatives.

8. **Informed Consent**
The risks and benefits of treatment were explained. Verbal consent was obtained from the patient. The possible need for future endodontic treatment of the treated teeth was explained, as was the need for an occlusal guard appliance. The patient was leaving for a vacation soon, and wished the restorative treatment to be performed in one appointment.

**TREATMENT**

**A. Treatment Objectives**

**Strategy**
Utilization of an Er:YAG laser to enable treatment in one session, with minimum discomfort and maximum conservation of the dental tissue.

**B. Laser Operating Parameters**

- Er:YAG laser used: Opus Duo E (Opusdent, Yokneam, Israel)
- Wavelength: 2940 nm
- Delivery system: hollow waveguide with angulated handpiece
- Emission mode: Free-running pulsed
- Spot size: 1300 µm
- Energy per pulse: 400 mJ
- Hz: 12 pulses per second
- Average power: 4.8 W
- Water cooling used at all times
- Total time: 13 minutes of laser energy exposure.

**C. Treatment Delivery Sequence**
The following safety measures were conducted. A test-fire of the laser was performed to verify correct operation and patency of the hollow waveguide delivery system. A safety area check (including only required personnel present, safety warning signs posted, and minimal reflective surfaces) was carried out. The patient and all personnel within the above-mentioned safety area were issued protective glasses. High-volume evacuation was used for tissue cooling and suction of removed tissue.

No anesthetic agent was used.
The laser tip (1300-µm Sapphire Noncontact Tip™) in noncontact mode was brought 2 to 3 mm from the dental surfaces using an average power of 4.8 Watts (400 mJ, 12 pps). Dentin preparation and enamel etching were achieved on each of the affected teeth (Figures 8, 9, 10, and 11). The teeth were then restored with self-etching adhesive (Xeno® III, Dentsply, York, Pa.) and a hybrid composite (Spectrum TPH, Dentsply) (Figures 12 and 13) which was photopolymerized with a light-emitting diode handpiece. A postoperative panoramic X-ray was taken (Figure 14).

The patient reported no discomfort during and after the procedures.

D. Postoperative Instructions
The patient was asked to continue with the desensitizing treatments (Desensin, Dentaid BeNeLux, Houten, Netherlands) and return for follow-up in one month.

E. Immediate Complications
There were no complications during or after treatment and no side effects were observed.

F. Prognosis
All objectives of treatment were met and the prognosis was considered excellent.

G. Treatment Record
All the information of the treatment was stored in the clinical record of the patient.

FOLLOW-UP CARE
A. Assessment of Treatment Outcome
Follow-up assessment was carried out at one month (Figure 15) and three months (Figures 16 and 17). The patient reported improvement in the initial symptoms.
B. Complications
There were no side effects or complications.

C. Long-Term Results
At three months, the teeth were comfortable and tested vital. The patient will be monitored for bruxism habits and possible fabrication of an occlusal guard appliance.

AUTHOR BIOGRAPHY
Dr. Alberto Trigas received his dental degree from the Faculty of Medicine and Dentistry, University of Santiago de Compostela, Spain. He is a practicing general dentist in Carballino, Ourense, Spain. Dr. Trigas is a member of the Spanish Society of Oral Surgery (SECI), the Spanish Society of Periodontology and Osseointegration (SEPA), the European Federation of Periodontology (EFP), the Spanish Society of Lasers in Dentistry (SELO), the European Society for Oral Laser Applications (ESOLA), and the Academy of Laser Dentistry (ALD). He has completed his Advanced Proficiency in the Er:YAG laser wavelength. Dr. Trigas may be reached by e-mail: clinicatrigas@ya.com.

Disclosure: Dr. Trigas has no financial relationship with any dental laser manufacturer.
The Use of an Er:YAG Laser (2940 nm) in Periodontal Surgery

Raminta Mastis, DDS, St. Clair Shores, Michigan


PRETREATMENT

A. Outline of Case

1. Full Clinical Description

A 52-year-old female patient presented with swelling and drainage of the lower left molar area. She had been treated for a similar flare-up 6 months earlier with a debridement and curettage of the furcation area with hand instrumentation under local anesthetic followed by a 10-day regimen of antibiotics. Other than hormone replacement therapy and occasional use of antihistamines, the patient was currently not taking any medications and her medical history was noncontributory.

Clinical examination revealed reddened and swollen gingiva which was tender to palpation and showed evidence of purulent drainage on the buccal aspect of tooth #19. Dental history included root canal therapy of tooth #19 (for treatment of abscess and severe pain), with the subsequent restoration of the tooth with a post and core followed by a porcelain-fused-to-metal crown two years ago. The patient also had a history of periodontal vertical bone defects at least in part related to her skeletal openbite occlusion, with only posterior teeth in contact. The patient did not complain of any TMJ-related symptoms and noted that her previous dentist had made her an occlusal guard, which she used to wear, but had not worn for several years now.

The patient was extremely motivated to try to save the tooth, recognizing that treatment alternatives / restorative options either did not offer a significantly better prognosis or were not financially feasible.

2. Radiographic Examination

The panoramic radiograph revealed generalized horizontal bone loss. A periapical radiograph of tooth #19 revealed radiolucency in the furcation area, indicating bone loss below the level of the furcation. Tooth #19 had evidence of root canal treatment, with satisfactory fill to apices. In addition, some evidence of vertical bone loss from the buccal furcation toward the mesial root apex suggested the possibility of fracture. In another area, the patient displayed radiographic signs of a vertical bone defect associated with endodontically treated tooth #3.

3. Soft Tissue Status

Although the patient had suffered generalized horizontal bone loss related to periodontitis and pockets ranged from 3 to 6 mm of neighboring teeth, the periodontal situation had been maintained and stable for several years, with no associated symptoms or noted mobility. Tooth #19 presented with a 9-mm pocket on the mesiobuccal aspect, especially in the furcation area with slight mobility attributed to swelling and infection.

4. Hard Tissue Status

Tooth #19 was nonvital, with a history of root canal treatment just over two years ago. The root canal filling appeared satisfactory. The tooth had only minor mobility, attributed to the presence of infection. This first molar tooth was the terminal tooth in the arch. Opposing teeth #13 and 14 were restored with porcelain-fused-to-metal crowns. The patient exhibited evidence of bruxism by the wear patterns on occlusal surfaces. Excessive occlusal forces were also attributed to the patient’s anterior open bite occlusion with only bicus-
CLINICAL CASE

5. Other Tests
The patient was referred to an endodontist for evaluation of tooth #19 for possible failing root canal treatment or root fracture. Due to the bone loss surrounding the tooth, the specialist gave a doomed prognosis, without specifically giving a diagnosis for the infection and recommended extraction as the only treatment option (Figures 1-4).

B. Diagnosis and Treatment Plan

1. Provisional Diagnosis
An infected tooth #19 with a 9-mm pocket with purulent drainage in the furcation area.

2. Final Diagnosis
Periodontal pathology associated with the furcation involvement of tooth #19, associated with generalized bone loss and possibly aggravated by a fracture due to possible excessive occlusal loads.

3. Treatment Plan Outline
It was proposed to use an Er:YAG laser to incise and raise a full-thickness flap for visualization of the defect, with the laser being used for debridement of the granulation tissue. Finally, a resin-reinforced glass ionomer would be placed in the furcation to correct the defect (reduce the level of the furcation and seal the furcation from possible fracture).

4. Treatment Plan Alternatives
Treatment alternatives included the following:
- The use of traditional surgical procedures including a scalpel for the incision and raising the flap, followed by hand instrumentation with curettes. Extraction of the tooth and restoring with an implant; however, this was not financially realistic for the patient at this time.
- A removable partial denture for a single-tooth replacement with consideration of the patient's unique occlusal scheme was also a questionable alternative and posed compromises.
- In consideration of these restorative options, an attempt to save the tooth was the most conservative approach.

5. Indications for Laser
Laser incision offers improved visualization of the surgical site as well as less postoperative discomfort. Use of the laser is an asset for the debridement of granulation tissue because of this tissue's higher water content compared to surrounding tissues (i.e., bone, root surfaces) and can therefore at low energy settings selectively debride the diseased tissue at the site. Use of the laser is an asset over traditional means because of its aid in reducing the bacterial load.

6. Contraindications for Laser
There were no absolute contraindications for the use of the laser on this patient. Proper energy control needs to be used for the tissues to be treated both to avoid tissue overheating and also to prevent collateral thermal damage to adjacent tissue structures. Care must be taken to avoid an air embolism in a flapped surgical site by directing the air away from the attachment.

7. Precautions
The Er:YAG laser wavelength easily interacts with both hard and soft tissue, so care must be taken to avoid interaction with any associated healthy tissue, especially hard dental tissue. It is important that adequate water spray be used during soft tissue ablation to avoid thermal damage through charring.

8. Informed Consent
The patient was well informed about the guarded prognosis for this tooth even with laser surgery and that this was a final effort to try to save the tooth. No guarantees were offered and the patient was advised that failure would result in extraction of the tooth. The patient remained motivated to try treatment before committing to loss of tooth. Written and verbal consent were obtained from the patient to proceed with the proposed surgical procedures and allow the use of photographs for educational purposes.

TREATMENT

A. Treatment Objectives
Strategy
The Er:YAG laser would be used to create a vertical incision of the gingival tissue and assist in raising a full thickness flap for access to the surgical site. The laser would be used to debride the granulation tissue in the furcation area. The objective was to decontaminate the lesion, correct or minimize the defect (with the placement of a filling to seal the furcation area and thus make it more cleansable and easier to maintain) and allow for healing of the infected site.
B. Laser Operating Parameters
A 2940-nm wavelength, free-running pulsed Er:YAG laser (HOYA ConBio, Fremont, Calif.) was used. The energy was delivered through an optical zirconium aluminum fluoride fiber to a 600-micron quartz tip with an 80-degree curve.

For the gingival incision, a setting of 10-Hz repetition rate and 65 mJ per pulse was used initially without water, but water was added as depth of incision approached bone, in order to reduce thermal injury, for a total of 20 seconds. The tip was kept perpendicular to the surface and in noncontact mode (about 0.5 mm away from surface). For the debridement of the granulation tissue, a combination of noncontact and contact mode was utilized. The average power for the soft tissue procedures was 0.65 Watt.

C. Treatment Delivery Sequence
All safety precautions, which included laser protective eyewear for the patient, doctor and assistant, were verified by the laser safety officer. Local anesthetic was administered with an inferior alveolar nerve block and allowed to take effect. The laser was set to the soft tissue settings and test-fired outside the mouth. Depth of the tissue was verified with bone sounding. With no water a vertical incision was initiated on the mesial aspect of the interdental papilla between teeth #20 and 19, extending approximately 1 cm apically. As the depth of the incision increased, water was added to aid in cooling of underlying bone and reduce thermal injury. No sign of charring was observed. A noncontact mode was used. The laser was used to aid in the release of the attached gingiva by directing the tip (with water and soft tissue settings) in the pocket perpendicular to the surface of the tooth. A periosteal elevator was used to reflect the full-thickness flap. The granulation tissue was debrided with the laser in short intervals, utilizing both contact and noncontact mode. This was alternated with hand instrumentation with periodontal curettes to aid in bulk tissue removal. High-speed suction was used throughout the procedure for the purpose of cooling, removing plume, and evacuation of debris and water.

The furcation area was curetted and dried. There was no clinically visible sign of fracture. A resin-reinforced glass ionomer restorative (Fuji II LC, GC America Inc., Alsip, Ill.) was mixed, placed on the tooth in the furcation, and sculpted to artificially lower the furcation level prior to light curing. Two silk sutures were placed for primary closure of the surgical site and a periodontal dressing (Coe-Pak™, GC America Inc.) was applied (Figures 5-9).

D. Postoperative Instructions
The patient was instructed to try to retain the periodontal dressing covering the site to minimize disturbance until her next appointment. She was instructed to use gentle warm salt water rinses 4-6
times daily in the area and to maintain oral hygiene of the rest of her teeth. A prescription for ibuprofen (Motrin™) 800 mg was written for use if she noticed pain. The patient was advised to call the office immediately if she noted any adverse reactions or problems.

E. Complications – Types, Events, Management
The patient was contacted the following day and she reported no discomfort and had no need to use any analgesics. The patient was seen one week after the surgery. The periodontal dressing was taken off and sutures were removed. The healing was progressing satisfactorily and the patient reported no complaints of discomfort. The patient was instructed to resume normal function and oral hygiene home care. At the three-month recall visit, an occlusal guard was delivered. The patient reported she had been eating on the side with no problems.

F. Prognosis
There was no sign of complications related to the procedures, and the prognosis for the gingival healing from the incision was determined to be excellent. The prognosis for the healing of the lesion in the furcation is good; however, the overall prognosis for long-term retention of tooth #19 remains guarded.

G. Treatment Records
All treatment data, including the type of laser used, operating parameters, the materials used, the intraoral photographs and radiographs, were recorded along with the written documentation.

FOLLOW-UP CARE
A. Assessment of Treatment Outcome
The patient was asked to return at one-week, two-week, six-week, three-month, and six-month intervals. She was contacted the next day and there was no report of any discomfort. At the one-week follow-up, the periodontal dressing and the sutures were removed, the tissue looked pink, and the incision was healing satisfactorily. The patient had no complaints; in fact, she said she was feeling better than she had been for a long time. At the second-week follow-up, the tissue continued to heal satisfactorily, with no evidence of swelling or drainage.

At the six-month follow-up, the tissue looked pink and the tooth was firm. Periodontal probing produced 3-4 mm pocketing near the surgical site, with no bleeding or exudate. Radiographs were hopeful for healing of the pathology with no recurrence of infection. Although this was a guarded case from the outset (in fact, it was doomed by the specialist), at the six-month follow-up visit the prognosis was hopeful and the patient was pleased (Figures 10-15).
B. Complications
At the six-week interval, the patient had resumed normal function, although she had noted some hesitancy to chew tougher foods. At the three-month recall, a limited occlusal equilibration was performed with impressions for a mandibular occlusal guard, which was delivered one week later.

C. Long-Term Results and Prognosis
The long-term outlook for the furcation-involved tooth remains uncertain in this case because of the compromised bony support on a heavily loaded occlusal surface due to the patient's occlusion. However, the elimination of infection and healing following laser bacterial reduction of the lesion seems promising in providing a hopeful environment for retaining the tooth by improving cleansability of the furcation area (and sealing a possible furcation fracture). Efforts to manage the occlusal forces with an occlusal guard will help the long-term prognosis.

AUTHOR BIOGRAPHY
Dr. Raminta Mastis received her dental degree from the University of Illinois College of Dentistry in 1987. She maintains a private practice in St. Clair Shores, Michigan, focusing on integrating cutting-edge technology in general dentistry. She is a member of the Academy of Laser Dentistry and has Standard Proficiency certification in Er:YAG, Er,Cr:YSGG, diode, and CO₂ laser wavelengths. In 2006 she achieved Advanced Proficiency in the Er:YAG laser wavelength. Dr. Mastis may be reached via e-mail: mastis@bignet.net.

Disclosure: Dr. Mastis has no commercial relationships relative to this case study.
Gingival Recession in a Lower Incisor: Frenectomy and Mucogingival Regeneration Using an Er,Cr:YSGG Laser

Giovanni Olivi, MD, DDS, Rome, Italy


SYNOPSIS
An Er,Cr:YSGG laser was used to revise a lower anterior frenum and for gingivoplasty of the surrounding soft tissue. Similar to the Er:YAG’s ability to remove thin layers of tissue at a time, this laser is well suited for contouring gingival tissue.

PRETREATMENT
A. Outline of Case
1. Full Clinical Description
   MEDICAL HISTORY
   A 19-year-old white female presented for dental treatment. The patient’s past medical history was uneventful, with no serious illnesses. She reported no allergies or any long-term use of medication.
   DENTAL HISTORY
   The patient had a history of good oral health, but with six filled teeth.
   She complained of heat and cold sensitivity at the lower right central incisor when drinking and brushing.
   Occlusion: The occlusal relationship was Angle’s Class I with a left lateral deviation of the median line (Figures 1-3).
   TMJ: Pulpation of both temporo-mandibular joints revealed no evidence of pathology throughout all normal jaw movements.

2. Radiographic Examination
   The pretreatment X-rays (Figures 4-5) showed no periodontal problems and no infrabony pocketing. In addition, the radiographs confirmed the presence of fillings at teeth #2, 14, 15, 18, 19, and 31, with no evidence of caries.

3. Soft Tissue Status
   Examination revealed a good general status of gingival tissue throughout, with the exception of recession associated with tooth #41, exposing some root structure. It was considered that, generally, the gingival tissues were rather thin (Figure 6).
   Plaque control and oral hygiene was generally good, with some

Figures 1-3: Preoperative, full-mouth views
Figures 4-5: Preoperative, full-mouth radiographs
supragingival calculus associated with the lingual aspect of the lower incisors.

Soft Tissue Probing Test: Probing depth was 1-2 mm without bleeding in all quadrants (Figure 7).

4. Hard Tissue Status
MAXILLARY ARCH
Teeth #2, 14, and 15 were restored with composite filling material.

MANDIBULAR ARCH
Teeth #18, 19, and 31 were restored with composite filling material.

TOOTH VITALITY TEST
All teeth were within normal limits for pulp testing, with the exception of tooth #25 which appeared hypersensitive to thermal testing.

MOBILITY
There was no evidence of tooth mobility.

PERCUSSION
No pain to percussion was evident.

5. Other Tests
No other tests were carried out.

B. Diagnosis
1. Provisional Diagnosis
With regard to any proposed dental treatment, the provisional diagnosis was summarized as gingival recession associated with tooth #25.

2. Final Diagnosis
Following radiographic and other examination, the provisional diagnosis was confirmed: Excessive frenal traction of thin gingival tissue biotype at the buccal margin at tooth #25. This development may also have been exacerbated through incorrect tooth brushing.

3. Treatment Plan Outline
The treatment plan would involve the following stages:
   a. One session of hygiene (ultrasonic scaling, no laser) to prepare for laser surgery
   b. Fluoride application for caries prevention
   c. Laser incision of lower frenum
   d. Laser dissection of deep connective fibers
   e. Releasing laser incision of the mucogingival line from teeth #26 to 24
   f. Laser elimination of the epithelium of overlying mucosa to retard its regrowth.

4. Indications for Treatment
Treatment: Elimination of the excessive frenal traction associated with tooth #25 to improve oral hygiene and eliminate thermal discomfort.

   Laser: Laser treatment of soft tissue can be achieved hemostatically, with an associated elimination of bacterial contamination. The technique is very easy to perform with rare complications and needs only one session to complete treatment. Used correctly, laser surgery can offer reduced postoperative discomfort.

   Wavelength: The Er,Cr:YSGG (2780-nm) laser wavelength is well absorbed by water and hydroxyapatite chromophores and interacts both with soft and hard tissue. This wavelength can be used to treat soft tissue in a very superficial mode due to its surface ablation. The relatively low absorption of this wavelength in pigmented tissue can result in some bleeding, although the fibrous nature of the frenum would suggest that such a problem would be unlikely.

5. Contraindication for Treatment
Treatment: The patient’s home care must be very good (correct brushing technique, flossing, and fluoride mouthwash) to prevent recession relapse.

6. Precautions
The Er,Cr:YSGG laser wavelength easily interacts with both hard and soft tissue, so care must be taken to avoid interaction with any associ-
ated healthy tissue, especially hard dental tissue. It is important that adequate water spray be used during hard tissue ablation, to avoid thermal damage through charring.

7. Treatment Alternatives
Alternative treatment protocols can be summarized as follows:
- Conventional, scalpel-based surgical technique with an open flap
- Guided tissue regeneration (GTR), using a lateral sliding and coronally advanced flap or free gingival or connective graft.
These procedures would have a longer subsequent healing period and greater risk of postoperative complications.

8. Informed Consent
The treatment plan was fully explained to the patient and all associated risks were outlined. A written consent form was signed by the patient in the presence of a witness. The consent form was retained in the treatment notes.

TREATMENT
A. Treatment Objectives
Use an Er,Cr:YSGG laser (wavelength 2780 nm) for (1) incision and removal of the frenum and dissection of deep connective fibers to completely eliminate traction on the attached gingiva, and (2) incision of the muco gingival line and elimination of the epithelium of the surrounding mucosa to retard its regrowth.

B. Laser Operating Parameters
The laser used was an Erbium, Chromium:Yttrium-Scandum- Gallium-Garnet (Er,Cr:YSGG) device (Waterlase Millenium, Biolase, San Clemente, Calif.). The operating features are as follows:
- Wavelength: 2780 nanometers
- Emission mode: free-running pulsed
- Pulse width: 140 microseconds
- Repetition rate: fixed at 20 pps
- Power: 0 to 6.0 Watts

Laser settings per procedure:
- In-contact, 0-0.5 mm
- Frenum cutting: 1.25-1.5 Watts, 62.5-75 mJ/pulse, air 20% / water 15%, T4 tips (400 microns)
- Mucogingival cutting: 1.25-1.5 Watts, 62.5-75 mJ/pulse, air 20% / water 15%, T4 tips (400 microns)
- Frenum dissection: 1.5-1.75 Watts, 75-87.5 mJ/pulse, air 20% / water 15%, Z4 tips (400 microns)
- Epithelium removal: 1.0 Watt, 50 mJ/pulse, air 20% / water 15%, G6 tips (600 microns)

Total time taken:
- Frenum cutting: 2 min
- Frenum dissection: 5 min
- Mucogingival cutting: 2 min
- Epithelium removal: 2 min
- Total time for procedure: 11 min.

C. Treatment Delivery Sequence
Preliminary to patient treatment:
- Secure operating room, place proper laser-in-use warning signs
- Set up laser and test proper laser operation. Test-fire laser in a styliform tray, using all safety measures and minimum power
- Supplies dispensed, equipment and sterile instruments arranged

Acting upon advice received, the patient requested the use of a local anesthetic: 0.8 ml of local anesthetic (Articaine with adrenaline 1:200,000) was administered submu cosa1 at appropriate sites in the lower labial sulcus and buccal mucosa.

1. The laser handpiece with a 400-micron conical sapphire tip was used in contact (0-0.5 mm) mode. The incision of the mucogingival line was performed, using the power parameters outlined above. A mapping of the incision line was first outlined as a series of small laser-induced spots on the mucosa, followed by the development of the full-thickness incision. Care was taken to control the depth of the incision.

2. The laser handpiece was positioned in contact with the lower frenum (0.5 mm) at the parameters outlined above. Incision and dissection were carried out (Figure 8).

3. The epithelium was removed using a defocused noncontact mode and G6 tip.
D. Postoperative Instructions
The patient was instructed to call if any problem were to occur and was called after 24 hours. Postoperative analgesia was prescribed. The patient was instructed to continue home care, rinse twice a day with 0.12% chlorhexidine mouthwash, and light tooth-brushing was prescribed 2 weeks after the surgery.

E. Complications, Types, Management
No complications were encountered during or immediately after the provision of laser surgical treatment.

F. Prognosis
Generally, frenum removal performed with the laser has a very good prognosis. In this case it was believed that a similar outcome could be expected.

G. Treatment Records
All procedural details, both gener-
ally and specifically with reference to the laser use, were entered in the patient’s treatment notes, along with the consent details, radiographs, and chartings. As such, the treatment records reflected the treatment outlined above.

FOLLOW-UP CARE
A. Assessment of Treatment
The patient was followed up at 1 and 2 weeks, 1 month, and checked again at 6, 12 and 24 months. At the 1-week recall, granulation tissue appeared in the wound, and the marginal gingiva, near the surgical site, had started to creep coronally (Figure 9).

At the 2-week recall the formation of a scar seemed to recreate the initial recession (Figure 10).

At 45 days the initial maturation of the regenerated gingiva had allowed the gingiva to creep over the root (Figure 11).

At 6 months the healing was complete. The gingiva was not inflamed but the aspect was slightly different from normal attached gingival in that it was thicker and attached to the deeper planes. The probing showed a new coronal attachment (1-2 mm) (Figure 12). No thermal hypersensitivity of the associated teeth had developed.

B. Complications
No complications were encountered.

C. Long-Term Results
At 12 months and 18 months the healed surgical site appeared stable. The root of tooth #25 remained covered, offering a good esthetic and functional result (Figures 13-18).

D. Long-Term Prognosis
Prognosis of treatment was good. The patient maintained good oral
hygiene and was pleased with the esthetic and functional result.

**AUTHOR BIOGRAPHY**

Dr. Giovanni Olivi practices in Endodontics and in Esthetic and Restorative Dentistry in Rome, Italy. He has been interested in microscopic and laser dentistry since 2000. He is an active member and Master of Academy of laser dentistry(ALD), as well as a member of SOLA, WFLD and WCLI. He is a founder and Board member of the International Academy of High Tech (IAHT). He is an active member of the Italian Academy of Microscope Dentistry (AIOM).

He has been a speaker in national and international laser conferences and is a consulting teacher for Masters in Laser Dentistry at university courses in Genoa, Florence, and Rome, as well as the same role for the European Masters degree in Oral Laser Applications (Emdola) at the University of Nice. Dr. Giovanni Olivi is the recipient of the 2007 Leon Goldman Award, presented for clinical excellence in laser dentistry.

_Disclosure: Dr. Olivi is a Laser Teacher at Master Laser Course of the University of Genoa DI.S.T.BI.MO., and is a Board member (without compensation) of IAHT._

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*Figure 18: Postoperative periodontal probing chart*
Crown Lengthening: Removing Hard and Soft Tissue with an Er:YAG Laser

Alfred D. Wyatt, Jr., DMD, College Park, Georgia


SYNOPSIS
An Er:YAG laser was used to perform closed flap osseous and gingival crown lengthening for access to a carious lesion on a maxillary molar. This wavelength is well suited for bone removal as well as for gingival surgery, targeting the water of both of those tissues.

PRETREATMENT

A. Outline of Case

1. Full Clinical Description
A 24-year-old patient presented to the office after “breaking the back of my back tooth off while chewing some gum” (Figure 1). The patient had been treated several times in the office and had been previously informed of the need for a crown or bridge on this particular tooth. The patient stated that she had sinus problems and anemia, but nothing that needed to be addressed prior to treatment. Although she had received several treatment plans, the majority of the patient’s visits tended to be episodic. The patient maintained good oral hygiene and periodontal health and exhibited no occlusal or TMJ abnormalities. The patient had a Class I skeletal relationship.

2. Radiographic Examination
A previous panoramic radiograph showed several endodontic therapies, some which had not received crowns as recommended (Figure 2). Interproximal bone height was satisfactory. No abnormal radiolucencies or radiopacities were observed. The periapical radiograph of the affected tooth did not give a good indication of the severity of the fracture (Figure 3).

3. Soft Tissue Status
No suspicious areas were observed in the vestibule, floor of the mouth, attached gingival, or buccal mucosa. The periodontal probe depth readings were 3 mm or less throughout the mouth. The gingival tissue around the affected tooth had begun to extend into the fractured area.

4. Hard Tissue Status
Bone height and density observed on panoramic and periapical radiographs were within normal levels. Tooth #2 exhibited a fracture of the lingual that extended below the gingival margin into the bone.

5. Other Tests
The patient exhibited no occlusion or mandibular range-of-motion difficulties.

B. Diagnosis

1. Provisional Diagnosis
The lingual cusp of tooth #2 was fractured below the gingival margin and crestal bone.

2. Final Diagnosis
Fracture of the mesiolingual and distolingual cusps of tooth #2 with 2 mm of gingival hyperplasia. The fractured tooth structure extended through the soft tissue attachment to the bone.

3. Treatment Plan Outline
The primary objective was to restore tooth #2 using an Er:YAG laser in the following manner:
   a. Remove gingival tissue overgrowth from the lingual aspect of the tooth.

Figure 1: Preoperative view of the fractured lingual cusps of tooth #2

Figure 2: Preoperative panoramic radiograph

Figure 3: Preoperative periapical film showing existing endodontic treatment and intact surrounding osseous tissue.
b. Establish a definitive lingual margin on the tooth by reducing lingual crestal bone.
c. Fabricate a direct post and core.
d. Construct a porcelain-fused-to-metal (PFM) crown for final restoration until the patient desires a fixed partial denture.

4. Indications
The use of the Er:YAG laser can be used for crown lengthening the hard and soft tissues to re-establish proper biological width for placement of a restoration.

5. Contraindications
The new crown-root ratio must be acceptable and provide a good prognosis if crown lengthening is to be performed. Due to the good periodontal health of the patient, there were no contraindications for performing the procedure.

6. Precautions
When removing and contouring the gingival tissue, the laser handpiece tip must be angled carefully to avoid removing tooth structure beyond the intended margins of the preparation. Water spray is usually not used for soft tissue removal, but must be turned on when contouring the bone. The air component of the spray should be turned off to minimize the possibility of an air embolism developing in the soft tissue flap.

7. Treatment Alternatives
Alternatives to treatment methods include the use of traditional surgical methods utilizing periodontal knives for the soft tissue and rotary handpieces for the removal of bone.

8. Informed Consent
Upon receiving a full explanation of the procedure, the patient gave verbal consent to perform the proposed treatment.

TREATMENT
A. Treatment Objective Strategy
The primary objective is to perform the majority of the procedure using the Er:YAG laser, including removal of hypertrophic gingival tissue as well as the reduction of crestal bone to create a lingual margin in tooth structure for a crown.

B. Laser Operating Parameters
An Er:YAG laser (DELight, HOYA ConBio, Fremont, Calif.) with a wavelength of 2940 nm was used with its fiber delivery system and a 600-micron quartz tip. It operates in the free-running pulse mode with a pulse duration of 300 msec. The laser was used at 30 Hz, 70 mJ, 2.1 W without water spray and also at 25 Hz, 245 mJ, 6.1 W with water spray during the procedure. The tip was used in both contact and noncontact (defocused) modes.

C. Treatment Delivery Sequence
Prior to commencing the procedure, the patient was familiarized with the process and verbal informed consent was obtained. The patient was anesthetized with 2 caprulles of 2% lidocaine with 1:100,000 epinephrine. Subsequently, all laser safety precautions were performed.

Figure 4: Laser being used to remove gingival tissue

Figure 5: Gingival tissue removal completed

Figure 6: Completed osseous crown lengthening and preformed post placed into palatal canal

These included but were not limited to the administering of laser safety glasses to the patient and operators, displaying laser hazard signage, and inspecting mechanical aspects of the laser. Once safety systems were in place, the laser was test-fired to ensure proper beam function and water spray delivery. The laser pulse rate was set to 30 Hz and the laser energy was set to 70 mJ, producing 2.1 W of power. High-volume suction was placed close to the target tissue site during operation. The laser handpiece was initially directed at a slight distance away from the targeted gingival tissue (defocused) and gradually moved closer until light contact occurred (Figure 4).

After the gingival tissue was contoured (Figure 5), the laser settings were changed to 25 Hz, 245 mJ (6.1 W) to remove the bone. The bone was ablated in noncontact mode with the tip about 0.5 mm away from the targeted site. The bone was contoured and the tooth margin placement was determined so that healthy biologic width could be maintained. An approximate restoration margin was established, and a core retainer (IntegraPost™, Premier Dental Products, Plymouth Meeting, Pa.) was placed into the prepared lingual canal (Figure 6) and cemented with glass ionomer cement (Fuji, GC America Inc., Alsip, Ill.). Subsequently, the core was built using a compomer material (Figure 7). On the patient’s next visit, the tooth was prepared to receive a PFM crown and the crown was successfully cemented.
CLINICAL CASE

D. Postoperative Instructions
The patient was told that the area may feel as though it had been burned by hot food, and mild analgesics such as ibuprofen or acetaminophen could be used for discomfort. No restrictions were placed on eating.

E. Complications
No complications occurred during or after the procedure.

F. Prognosis
The prognosis for the success of the restorations following the procedure was considered to be excellent.

G. Treatment Records
Treatment records indicate laser type, settings, and materials used in the procedure.

FOLLOW-UP CARE
A. Assessment of Treatment Outcome
One month after the crown lengthening procedure was performed, healing and contours around the teeth were determined to be excellent (Figure 8). The tooth was immediately prepared for a crown (Figure 9), and 2 weeks later the crown was inserted (Figure 10). Three months after the crown insertion (4 months after crown lengthening), the treated area was doing very well (Figure 11).

B. Complications
No complications were observed during or after treatment. The patient also made no mention of any problems or concerns.

C. Long-Term Results
Four months after the procedure, the restoration appeared sound and functional. The margins around the tooth as well as the health and texture of the gingival tissue were satisfactory. A postoperative radiograph (Figure 12) showed good margins of the crown. Figure 13 shows a 3-year postoperative view that demonstrates healthy periodontium.

D. Long-Term Prognosis
With quality oral hygiene and proper routine maintenance, the long-term stability of this tooth should be very good.

AUTHOR BIOGRAPHY
Dr. Alfred Wyatt, Jr. is a graduate of the Medical College of Georgia School of Dentistry where he serves as Associate Professor of Oral Rehabilitation. He maintains a private practice in College Park, Georgia. Currently, he serves on the Board of Directors of the Academy of Laser Dentistry as well as on the American Dental Association working group for laser usage. Dr. Wyatt presently utilizes Er:YAG and diode lasers in his practice and has attained Advanced Proficiency and Certified Educator Status through ALD. Dr. Wyatt may be reached via e-mail: doc2TH@bellsouth.net.

Disclosure: Dr. Wyatt has no financial connections with or interests in any dental companies.
The following abstracts and excerpts expand upon the “hard tissue ablation” theme of other articles in this issue. While the manuscript by Dr. Wolf Seka and colleagues on “Laser Ablation of Hard Dental Tissue” (pages 61-72) as well as the ALD’s Science and Research Committee’s Position Paper on “The Use of Laser Energy for Therapeutic Ablation of Intraoral Hard Tissues” (pages 78-86) focus primarily on major applications of currently available laser wavelengths (although not all of the wavelengths described are readily available to dental practitioners), the field of laser dentistry actually provides a long and rich history of research into the safety and effectiveness of laser-induced dental hard tissue ablation and caries removal, long the “holy grail” of laser pursuit in dentistry. We examine a few such studies of historical significance here.

**FIRST STUDIES**

It is no surprise that the first notable published report of laser experimentation in dentistry involved an examination of the effects of a laser on an extracted human tooth, as reported by Ralph Stern and Reidar Sognnaes in 1964, not long after Theodore H. Maiman demonstrated the first successful laser on May 16, 1960.¹

(Editors Note: T.H. Maiman passed away on May 5 of this year in Vancouver, BC at the age of 79. Cause of death was systemic mastocytosis, a rare genetic disorder. Readers interested in learning more about Maiman’s contributions are invited to review an article published in SPIE’s OE Reports in August 2000, based on an interview on the 40th anniversary of the laser’s development. The electronic version of the article, “Inventing the light fantastic: Ted Maiman and the world’s first laser” by Greg Friedman, is available at http://spie.org/x13999.xml, and was accessed by the editors on May 25, 2007.) As significant as their early investigations were, both Stern and Sognnaes realized the limitations of their available instrumentation. Their observations are summarized below.

Soon after their work, Leon Goldman (for whom the Academy of Laser Dentistry’s “Leon Goldman Award” is named) and cohorts were the first to publish a report on the use of a laser on a live human patient’s tooth (scheduled for extraction) exposed to 17 joules of laser energy. Of high historical interest, a portion of their 1965 report (which described results of both in vivo and in vitro studies) is provided below. Their results showed superficial destruction of the crown of the tooth and metal filling. While their experiment caused no harm to their human volunteer, it is noteworthy that the researchers were acutely aware of pertinent safety concerns for laser patients.

Stern, Sognnaes, and Goldman experimented with 694.3-nm ruby lasers, the only laser wavelength available in their era. In the coming years additional wavelengths and devices were developed, which gave rise to more investigations into the possibilities of hard tissue ablation via lasers.

**EXCIMER LASERS**

For example, in the late 1980s excimer lasers were first investigated for possible dental applications. Developed in the 1970s, excimer lasers use an inert gas (such as argon or xenon) and a reactive gas (such as fluorine or chlorine) which, when stimulated electrically under certain conditions, produce laser light in the ultraviolet wavelength range. In biological applications, pulsed excimer lasers can break molecular chemical bonds, cutting tissue with virtually no thermal effect on surrounding tissue, according to some researchers. As reported in 1988, Matthias Frentzen and others used an ultraviolet, 193-nm argon fluoride laser in an in vitro study to help determine whether that technology could be transferred to clinical practice. Frentzen proposed the possibility of selective caries removal.

Independently in the late 1980s, Roberto Pini and Tim Liesenhoff were among the first to study excimer laser endodontic applications using a 308-nm xenon chloride laser. Pini reported an apparent preferential etching of infiltrated dentin compared to healthy dentin in his in vitro studies.

In a 1992 report, Tim Liesenhoff of the Technische Universität in Munich, Germany used a 308-nm XeCl excimer laser for root canal preparation on 20 human patients.² He reported that no failures of the root canal treatments were found 6 months afterward. Both Pini and Liesenhoff recognized the value of flexible fiber-optic delivery systems for laser-assisted endodontics. Currently, excimer lasers are used primarily in...
ophthalmology to reshape the cornea and in lithography for semiconductor manufacturing. Their relatively large size and high cost, along with unresolved concerns over their possible mutagenic and cytotoxic effects, have limited their exploitation in dentistry. As Markolf Niemz of the University of Heidelberg points out, “the difficulty in judging the severeness of mutagenic effects [that might arise from excimer laser radiation] is due to the long follow-up periods during which maladies can develop.” Ongoing development may alleviate such concerns and make these devices practical for clinical dentistry.

Frentzen and Pini were not the only researchers to identify the value and prospect of selective removal of dental hard tissue via laser energy. Elsewhere in this issue, Wolf Seka’s article describes Peter Rechmann’s investigations into the selective ablation of calculus with a frequency-doubled 377-nm Alexandrite laser. This topic was treated before in Wavelengths (1998;6(4):10-11 and 2002;10(4):15-17). Additionally, so-called “free electron” and “ultrashort pulsed” lasers have been used in increasingly sophisticated fashion to help determine more precisely mechanisms and effects of laser-tissue interaction.

FREE ELECTRON LASERS

A free electron laser (FEL) is a type of instrument that produces laser energy by passing a beam of free (that is, not bound to an atom or molecule) electrons through a magnetic field to produce laser energy that can be tuned from microwaves, through infrared, visible, and ultraviolet, to X-rays. It is this tunability that makes the device attractive to the research community, allowing the possibility of examining the effects of a wide range of laser wavelengths from a single device on various substances. The practicality of the FEL for everyday clinical use is currently questionable at best, owing to its complexity and high costs of construction and operation. Free electron lasers are relatively few in number (there are five or so FEL operating user facilities in the United States) and are generally located in research institutions and universities.

James Hoke and colleagues used the FEL at Duke University in North Carolina to compare the effects of a 3.0-µm FEL on tooth structure with those of an Er:YAG laser. Their report, published in 1995, appears below. The authors conceded that “the amount of ablation of enamel per unit of time was not measured. In order for a technique to become clinically useful the speed of enamel removal will need to be evaluated.”

Edward J. Swift and fellows used a free electron laser tuned to a range of wavelengths from 3.0 to 9.2 µm, specifically targeted to phosphates, proteins, and water, to investigate effects on etching of bovine enamel. Under the conditions of their study, published in 2001 and abstracted below, they found FEL-assisted etching was insufficient for resin bonding, but commented on the value of the tunability of the free electron laser in dental research.

ULTRASHORT PULSED LASERS

Ultrashort pulsed lasers (USPL) are another special laser type of interest to dental researchers investigating their precision and negligible thermal and mechanical damage capabilities. In contrast to today’s CO₂ lasers, which typically operate in continuous wave or superpulsed (10³ to 10⁶ s range) emission modes, or free-running pulsed lasers (such as Er:YAG, Er,Cr:YSGG, and Nd:YAG) whose pulse durations are usually measured in milli- or microseconds (10⁻⁷ to 10⁻⁴ seconds), the pulse durations of USPL devices are typically measured in picoseconds (10⁻¹² s) or femtoseconds (10⁻¹⁵ s). One of the challenges in making USPL devices practical for the dental operatory is the development of a flexible delivery system able to convey and withstand the high peak powers (1 million Watts)⁴ that these engineering-intensive lasers can produce.

These challenges aside, in 1995 Markolf Niemz reported on the in vitro use of a 1053-nm Nd:YLF picosecond laser for cavity preparation. He suggested that selective caries removal is facilitated because he found the ablation rate of caries is higher than that of sound enamel, and the generated plasma spark can be spectroscopically analyzed in real time. He concluded: “A computer-controlled picosecond laser system could be used to establish whether all caries has been removed … Therefore, the Nd:YLF laser could serve as a universal system for both diagnosis and therapy of caries.”

Joseph Neev and colleagues used a 1053-nm Titanium-sapphire USPL to investigate the effects of femtosecond pulses on enamel and dentin in vitro. Their report, published in 1996, appears below. The authors state: “The advantages of the ultra short pulse systems combined with convenient delivery systems … and optical fiber-based tissue diagnostics … harbour the promise of a truly fast and efficient tool for precise ablation of hard tissue with negligible pain for the patient.”

In another article in the same Proceedings, Neev and colleagues’ comment on the issue of tissue ablation selectivity: “In preliminary work we have shown that USPL interactions are generally insensitive to tissue type. This fact, in combination with the high removal rates envisioned, poses the question of tissue selectivity and operation control…A “smart” system may be envisioned, in which a module combining feedback, control and automation will exploit several optical technologies to allow high precision and a very high degree of control.”

Neev continues: “Feedback devices operating in conjunction with the laser allow very precise control of ablation endpoints. Two examples of such methods are a) Tissue-differentiation diagnostics based on spectro-
scopic plasma emission signatures. A feedback loop stops laser delivery when the tissue characteristics change, or b) Optical Coherence Tomography (OCT) crater diagnostics. The crater depth is monitored continuously with the OCT fiber device."

Journal readers will recall the pertinence of the latter-described technology. Linda Otis presented an overview of Optical Coherence Tomography in the previous issue, and Craig Gimbel's identification of OCT’s anticipated use in early recognition of carious lesions in this issue, point to a bright, technologically enabled, future dental operatory. With continued development in lasers and real-time feedback technologies, the precision, control, and tissue discrimination capabilities envisioned by Niemz and Neev are becoming closer to clinical reality.

Hard tissue ablation investigations involving erbium, carbon dioxide, Nd:YAG, frequency-doubled Alexandrite, and other laser types can be found in the research literature in abundance. Currently, the only laser wavelengths cleared by the U.S. Food and Drug Administration for removal of tooth substance (or modification of its surface) are Er:YAG and Er:Cr:YSGG for caries removal, cavity preparation, and enamel roughening, and Nd:YAG for selective removal of enamel (first degree) caries.

The success of today’s laser dentists is to a large extent made possible by such ongoing research. From Stern, Sognnaes, Goldman, and their successor researchers, clearly, laser dentistry would not be realizing the current and numerous patient benefits without the foresight, imagination, and commitment of these and many other visionary investigators, engineers, and clinicians.

REFERENCES
LASER BEAM EFFECT ON DENTAL HARD TISSUES

Ralph H. Stern, Reidar F. Sognnaes
University of California School of Dentistry, Los Angeles, California
Proceedings and Abstracts of the Forty-Second General Meeting of the International Association for Dental Research,
March 19-22, 1964, Los Angeles, California

Dental hard tissues are cratered when subjected to laser beam exposure. An exploratory study has been undertaken with two types of laser exposures: laser A 5-20 joules beam energy with 10-30 milliradians beam width and a 39-mm lens for focusing; laser B 2-5 joules beam energy with 1-2 milliradians beam width and a 42-mm lens. The beam duration was approximately 1 millisecond per exposure, and the beam width at the focal point was less than 1 mm. Because of the narrower beam width, laser B resulted in essentially comparable effectiveness in spite of a lower energy output. Exposure of intact dental enamel to the laser beam caused a glasslike fusion of the enamel, which showed reduced birefringence under polarized light; it is being further studied for crystallographic alterations. When dentin was exposed to laser, comparable energies burned a more definitive crater, with evidence of charring due to its higher organic content. The reflecting power of dental enamel caused much laser beam deflection. This was well illustrated when the enamel margins of gold- and silver-alloy restorations were exposed to the same laser beam. In such cases the metals absorbed much more energy than the enamel, resulting in considerable destruction of the metal restorations. This difference in energy dissipation and related theoretical calculations suggests that limited pulpal temperature changes take place when the surface enamel is exposed to the laser beam. Efforts to fuse powdered substances with the enamel were handicapped by differentials in energy dissipation of the structures and by the impact power of the beam. The significance of the relatively amorphous glazing effect on the enamel merits further study. Future application will be dependent upon new types of laser beam instrumentation, with due regard to energy, duration of exposure, beam width and beam transmission (fiber optics).

EFFECT OF LASER BEAM IMPACTS ON TEETH

Leon Goldman, MD; John A. Gray, PhD; John Goldman, BSc;
Bernard Goldman, DDS; Robert Meyer
Cincinnati, Ohio
J Am Dent Assoc 1965;70(3):601-606

...To study lasing a tooth in a patient, we selected a right upper second molar of a volunteer. The molar was to be extracted an hour later. Two impacts were made directly on the crown of the tooth, and the tooth was sent for microscopic study. The impacts produced only superficial changes . . . . The volunteer felt no pain or sensation of heat when his molar was lased; however, a burning odor was evident on both impacts. This may have been due to organic deposits on the teeth, such as enamel cuticles and dried saliva. There was no damage evident on the lips, mouth or gingiva about the molar. Only a faint, bright red light was perceived by the patient through his closed, protected eyes. We are concerned, of course, about the effect of this transillumination on the retina through passage out of the target region about the soft tissue, the closed eyelids, the orbit and so forth.

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**CARIES REMOVAL AND CONDITIONING OF TOOTH SURFACES FOR ADHESIVE FILLING TECHNIQUES BY USING 193 nm – EXCIMER LASER – PRELIMINARY RESULTS**

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*Lasers in Dentistry. Proceedings of the International Congress of Laser in Dentistry, August 5-6, 1988, Tokyo, Japan*

Hajime Yamamoto, Kazuhiko Atsumi, Haruka Kusakari, Michio Shimakura, and Teruo Kayano, editors

Amsterdam: Excerpta Medica, 1989:235-240

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Essential precondition for hard tissue treatment with lasers is the removal of organic and inorganic components. The very high melting point of hydroxylapatite – main component of dental hard tissue – makes it nearly impossible to remove or dissect enamel and dentine with only gentle thermal effects. A new technology called photodecomposition of organic and inorganic material by UV-laser light seems to point out an alternative way of laser treatment in dentistry . . . . In our studies we used an (ArF) – excimer laser system ... emitting light of a wavelength of 193 nm in pulses of about 20 nsec. The output energy was about 200 mJ per pulse. The repetition rate could be varied from 1 to 50 Hz depending on the necessities of the experimental set up. The [tooth] specimen[s were] irradiated by the laser ... Cutting through a caries defect the ablation rate per pulse of caries dentine is up to 100 times higher than in unaffected dentine...In enamel photoablation leads ... to retentive surfaces ... With only gentle increasing of temperature it is possible to remove dental hard tissue using an 193-nm ArF excimer laser system ... Photoablation is a tissue-specific process and promotes a selective caries removal . . . . Beside these results it has to be conceded that further experiments have to confirm whether this new technology is an alternative method with striking advantages to dentistry.

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**LASER DENTISTRY: A NEW APPLICATION OF EXCIMER LASER IN ROOT CANAL THERAPY**

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We report the first study of the application of excimer lasers in dentistry for the treatment of dental root canals. High-energy ultraviolet (UV) radiation emitted by an XeCl excimer laser (308 nm) and delivered through suitable optical fibers can be used to remove residual organic tissue from the canals. To this aim, UV ablation thresholds of dental tissues have been measured, showing a preferential etching of infiltrated dentin in respect to healthy dentin, at laser fluences of 0.5-1.5 J/cm². This technique has been tested on extracted tooth samples, simulating a clinical procedure. Fibers of decreasing core diameters have been used to treat different sections of the root canal down to its apical portion, resulting in an effective, easy, and fast cleaning action. Possible advantages of excimer laser clinical applications in respect to usual procedures are also discussed.

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The purpose of this study was to evaluate the Mark-III free-electron laser as a means of etching enamel surfaces, with potential application to resin bonding. Methods: The FEL was tuned to wavelengths ranging from 3.0 to 9.2 \( \mu \text{m} \). Specific wavelengths that are resonantly absorbed by phosphates, proteins, and water were used. First, bovine enamel was polished and exposed to static FEL exposures. Lased enamel was examined using scanning electron microscopy (SEM). Additional bovine enamel specimens were exposed to FEL at similar wavelengths, but with rastering to create treated rectangular areas on each specimen. Surface roughness was evaluated using profilometry and atomic force microscopy (AFM). Composite was bonded to the lased enamel, and shear bond strengths were determined using an Instron universal testing machine. As a control, the surface roughness of, and shear bond strengths to, acid-etched enamel were determined. Results: Static FEL exposures caused changes in the enamel ranging from an etched appearance to pits, cracks, and frank cratering. The surface roughness of lased enamel was much greater than that of acid-etched enamel, and was qualitatively different as well. Shear bond strengths of resin to acid-etched enamel were significantly higher than bond strengths to lased enamel. Conclusions: Under the conditions used in this study, the FEL did not offer a practical and effective method of etching enamel for resin bonding. However, the ability of the FEL to deliver many specific wavelengths makes it an interesting tool for further research of laser effects on tooth structure.
Several laser systems for the removal of hard dental substances are currently under investigation. However, in most cases, such systems have been demonstrated to be inefficient or have led to undesirable thermal side-effects. This paper reports, for the first time, the removal of enamel and dentin by a picosecond laser system, a solid-state Nd:YLF laser. Very precise cavities can be obtained in the enamel and dentin of extracted human molars when laser pulses are distributed onto well-defined areas of the teeth. Scanning electron microscopy shows that the quality of the cavities is superior to that achieved by other laser systems. The cavity walls are very steep, and their surfaces are characterized by a sealed structure. In contrast to laser systems with longer-duration pulses, picosecond laser pulses ablate with less thermal damage to the surrounding substance. The results of dye penetration tests and polarized microscopy show that even mechanical shock-wave effects are negligible. When the Nd:YLF laser is applied to carious enamel, the ablation rate is found to be about ten times higher than for sound molars, thus making the Nd:YLF laser a caries-selective laser system.

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Lasers are currently limited in their ability to remove hard tissue. Furthermore, many laser systems, such as the long pulse infrared lasers used to ablate bone or hard dental tissue, also generate unacceptable heat levels and cause collateral tissue damage. Ultrashort pulse lasers, however, are highly efficient, quiet, and relatively free of damage. With recent developments now allowing operation at high pulse repetition rates, ultrashort pulse systems can yield significant material volume removal which can potentially match or even exceed conventional technology while still maintaining the minimal collateral damage characteristics. In this paper, laser pulses generated by a 1053-nm Ti:Sapphire Chirped Pulse Amplifier system were used, [and] the interaction characteristics of two pulse regimes with enamel and dentin [were] investigated: 350 fs pulse ablation of hard dental tissues is compared to the interaction of one nanosecond pulses. Ablation rates were characterized, and surface morphology and structure were evaluated using a scanning electron microscope. In contrast to nanosecond ablation, negligible collateral damage and highly efficient ablation characteristics were demonstrated [at 350 fs]. The potential for an efficient, selective, accurate, and damage-free operation was shown. ■

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