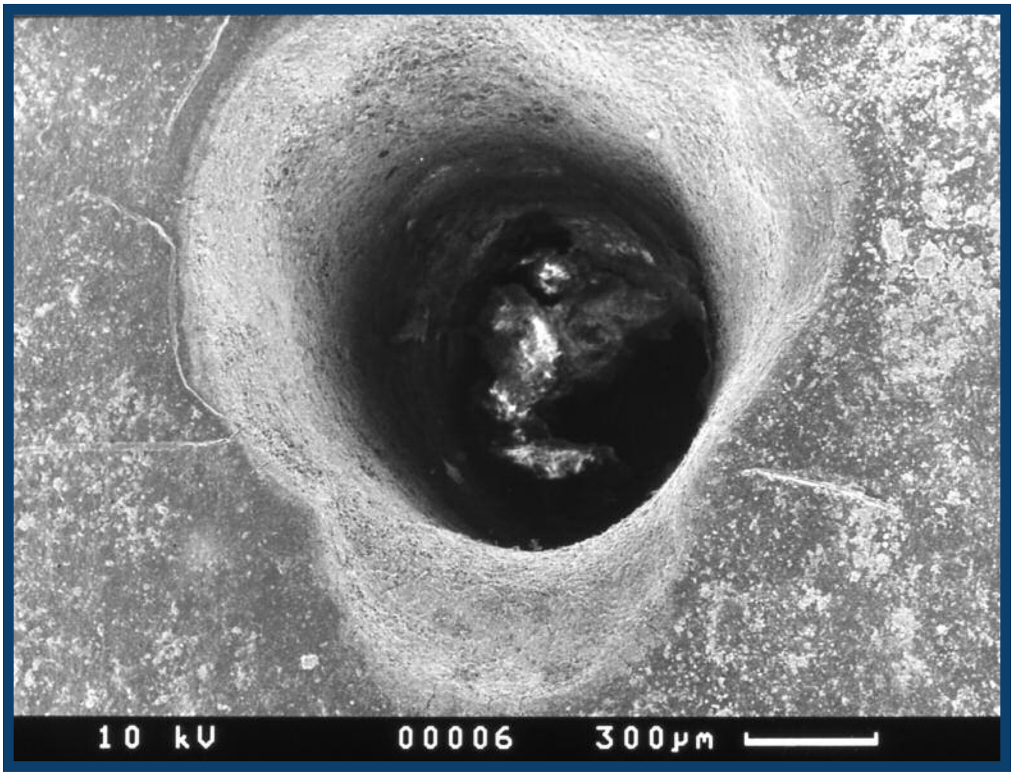
Journal *of* Laser Dentistry

The Official Journal of the Academy of Laser Dentistry 2007 • Vol. 15 No. 1



Ablation of bone by an Er:YAG laser. See the scientific / clinical review article on the use of lasers in bone surgery on page 9

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The Use of Lasers in Bone Surgery

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J Laser Dent 2007;15(1):9-13

SYNOPSIS

The use of suitable laser wavelengths in the cutting and ablation of bone during dentoalveolar surgery can offer distinct advantages over rotary instrumentation. It is essential to use the correct laser wavelength and power parameters to maximize predictable outcomes for bone surgery in dentistry. This article presents a review of this topic and provides examples from clinical practice.

ABSTRACT

The development of laser use in surgical dentistry has expanded to include all oral hard tissues, with accepted protocols for selected wavelengths being adopted. The purpose of this article is to demonstrate the composite nature of alveolar bone, the microstructure and processes commensurate upon bone damage, together with a review of the literature surrounding the applicable adjuncts of laser energy in the ablation of this tissue.

BONE STRUCTURE

Bone is a connective tissue derived from hyaline cartilage whose matrix, under the influence of calciferol, has been hardened by the deposition of calcium and phosphate to form a carbonated hydroxyapatite-like mineral, a carbonate substituted form of $Ca_{10}(PO_4)_6(OH)_2$, as the ground substance. Collagen remains the primary fibre in the matrix as it is in hyaline cartilage. Histologically, bone is composed of units termed Haversian systems or osteons in which concentric rings of osteocytes are arranged around a central blood vessel. The blood supply is via an arteriole-venule plexus within the peripheral periosteum, or via vessels contained within the bone substance. Cross-linkage between central canals is provided by Volkmann's canals. This matrix is maintained by osteocytes, the characteristic cells of bone.

Of concern to the dental surgeon, the dentoalveolar processes of the maxillary and mandibular bones are composed of an outer cortical plate, covered by periosteum and an inner complex of trabecular or cancellous bone. The cortical plate of the mandible is thicker than that found in the maxilla and remains fairly constant during adult life. However, the volume of cancellous bone in both jaws will reduce with time, following tooth extraction, indicating the purpose of this tissue as being supportive of the natural dentition.[1-3]

With the exception of the central neurovascular bundle, the mandible derives its blood supply from periosteal vessels and this assumes greater relevance with age, due to reduction in diameter in the inferior dental vessels. The extensive blood spaces found in the maxilla provide a more homogeneous blood supply in this bone, deriving from a central maxillary artery source. It therefore follows that, for surgical procedures that require the cutting or ablation of bone, care should be given to maintaining a contiguous relationship between periosteum and bone in the mandible, to prevent ischaemic atrophy.[4-5]

BONE HEALING

Following injury or surgery and in the absence of infection, the healing of alveolar bone is similar to that of osteoid tissue elsewhere in the skeleton. Early blood clotting allows a matrix for cellular and biochemical activity, whereby predominant osteoclastic action removes any damaged or dead mineralized tissue. This resorption stage will be longer in those cases where extensive damage has occurred, either due to trauma or thermal shock.[6] Following this, early growth of new bone occurs, through osteoblastic activity, to form a callous and later, woven bone, which over time is gradually remodeled to mature bone.

LASER ABLATION OF BONE

"Conventional" bone cutting with a bur or bone saw may result in a substantial temperature increase which far exceeds the threshold for protein breakdown and leads to possible sequestration of damaged bone elements.[7-8] Equally, studies on the effects of commercially available Nd:YAG and CO_2 lasers on bone show carbonisation and other structural damage.[9-12] Consequently, a "best practice" approach to bone ablation and cutting would suggest the need for a modality that would produce clinically acceptable rates of cutting without overheating. The current mid-infrared laser wavelengths, Er,Cr:YSGG (2780 nm) and Er:YAG (2940 nm), appear to offer such modalities.[13]

As with other hard tissue interaction, it is essential to maintain a co-axial water spray to prevent heat damage which would delay healing. Studies of the rate of thermal denaturation of collagen, a major component of bone tissue, show that above a critical temperature (74° C), the rate of collagen denaturation rapidly increases, causing rapid coagulation of tissue.[14-15] In general at temperatures above 60-80° C, collagen denaturation, coagulation, and necrosis are initiated. At temperatures above 100-300° C, there is the onset of dehydration, followed by carbonisation of proteins and lipids. Above a few hundred degrees, the protein of bone is pyrolised, leaving a carbon residue and possible structural changes in the mineral components.

The two applicable lasers for bone ablation are the Er:YAG (2940 nm) and the Er,Cr:YSGG (2780 nm) wavelengths. Both Er,Cr:YSGG and Er:YAG laser wavelengths are well absorbed in water, with the Er:YAG being somewhat more strongly absorbed in water than the Er,Cr:YSGG. This absorption in water is due to a relatively broad water band around 3,000 nm.[16-19] In addition, there is a small absorption at around 2,800 nm by the hydroxyl group of the (carbonated) hydroxyapatite mineral of the tissues[16,20-21] but this is far outweighed by the whole-water effects.

When incident laser energy is directed onto bone, it is absorbed by the prime chromophore, water. For both Er:YAG and Er,Cr:YSGG laser 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. Early study into the effect of the Er:YAG laser on bone showed that, like enamel and dentin ablation, tissue cutting is a thermally induced explosive process.[22-23] Through this mechanism, whole tissue fragments are ejected and a hole is cut in the bone, with little or no alteration to the mineral itself.

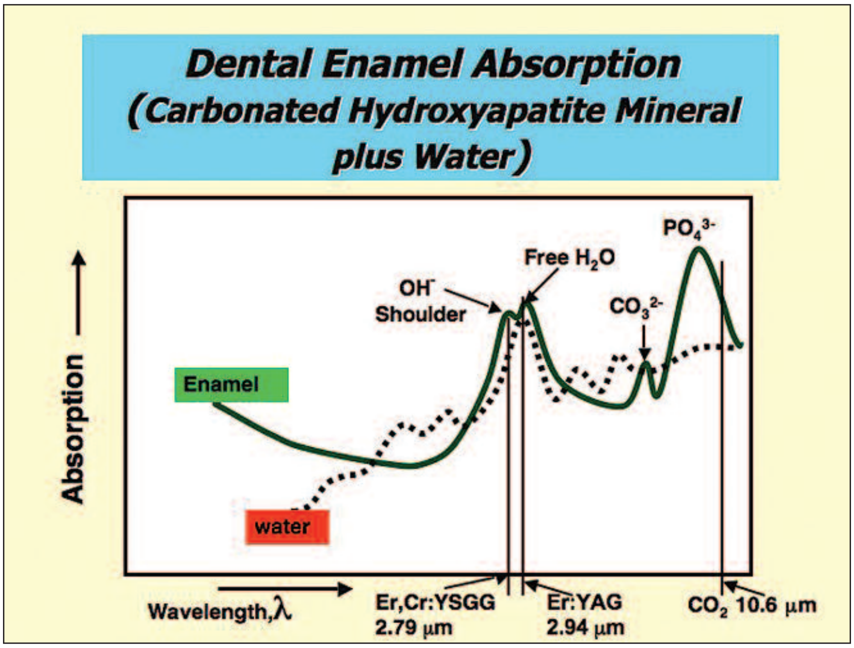

Figure 1: Absorption curve of enamel (carbonated hydroxyapatite (HA)) and emission wavelengths of the Er,Cr:YSGG, Er:YAG, and CO$_2$ lasers. Carbonated HA exhibits a small peak at approximately 7,000 nm, coincident with $(CO_3)^{2-}$ radical absorption. Water absorption is shown as a dotted line.

Figure 1 shows the absorption curve for dental enamel, the mineral component of which is a carbonated hydroxyapatite similar to that of bone, surrounded by water and a small amount of protein and lipid (inter-prismatic substance). The spectrum is not as complex as bone which also has the absorption bands attributed to groups in the collagen molecule. This figure clearly illustrates where the Er,Cr:YSGG and Er:YAG laser wavelengths are absorbed, primarily by the water. To a lesser extent the Er,Cr:YSGG will also be absorbed by the mineral due to the OH$^-$ ion that forms part of the mineral.

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. Ablation threshold values of 10-30 J/cm^2 have been recorded for bone of varying density.[24] In the author's clinical experience, with maxillary alveolar bone surgery, the speed of laser cutting is comparable to that of a surgical bur and slightly slower in the mandible, reflecting the greater mineral content of the latter's cortical bone. Such statements are subjective, especially as one study[25] reports slower cutting rates, although it does draw reference to bone ablation in the third molar region. What may be of greater relevance is the ability to carry out laser ablation within a clinically acceptable time frame. It is considered important that power parameters and water spray levels are adequate in order to prevent a "stall-out" effect of debris (where ablation products are allowed to accumulate and absorb laser energy). Laser settings of 350-500 mJ / 10-20 Hz (average power range 3.5-7.0 Watts) with maximal water spray appear to produce good ablation rates.

The ablation threshold for average bone is approximately 12-20 J/cm^2. As an example, Table 1 shows how easily that given fluence can be far exceeded when a beam diameter is used that is too small and/or the energy per pulse is too high.

It is essential, therefore, that correct power parameters are adopted so as not to produce unwanted heat effects in the target tissue site.

The poor haemostatic effect of current commercially available Er:YAG lasers can be used to advantage in the ablation of bone to ensure blood perfusion of the surgical site (Figures 2-3).

However, the ablation process using a pulsed laser and water spray results in a considerable spatter of blood, and precautions (eye protection and mask) are recommended. An additional risk may be the creation of an air embolism in the tissue, due to the air-induced water spray, although a review of the literature has not revealed an association. The ablation of bone using laser energy is associated with a level of noise, which represents the explosive interaction with chromophores. This has been measured in one study at between 99 and 121 dB.[26] However, in the author's experience, such sound level does not give cause for patient concern.

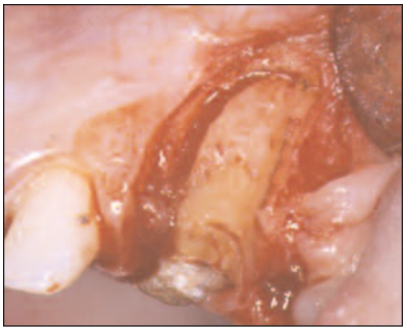

Figure 2: An Er:YAG laser has been used to cut through the buccal plate of bone (2940 nm, 800-μm beam diameter, 350 mJ per pulse / 10 Hz / 3.5 W average power).

Figure 3: Appearance following removal of the root. Note the accuracy of the cut and the free flow of blood.

Scanning electron microscope analysis of the cut surface of bone (Figures 4-5) reveals little evidence of thermal damage, and any char layer appears to be restricted to a minimal zone of 20-30 μm in depth.[27-28] Studies into the healing of laser-treated bone support the contention that the reduced physical trauma, reduced heating effects, and reduced bacterial contamination lead to uncomplicated healing processes when compared to conventional use of a surgical bur.[7,29-31]

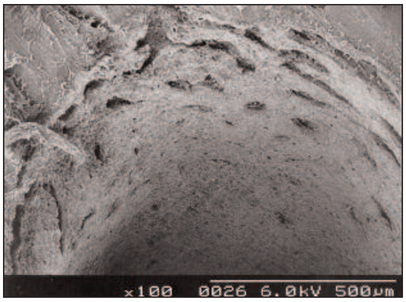

Figure 4: Scanning electron micrograph (SEM) of bone cut with an Er:YAG laser (2940 nm, 800-μm beam diameter, 400 mJ per pulse / 10 Hz / 4.0 W average power). Minimal thermally induced changes to tissue structure are seen.

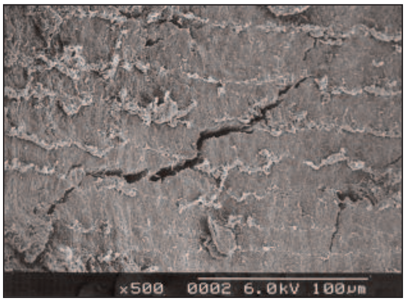

Figure 5: "Environmental" (wet) SEM of bone cut with a surgical bur (Ash #12 steel oral surgical bur). Note smearing and thermal cracking.

Beam Diameter	Energy Per Pulse		
	100 mJ	250 mJ	500 mJ
	Fluence		
300 μm	141 J/cm^2	353 J/cm^2	707 J/cm^2
600 μm	35 J/cm^2	88 J/cm^2	175 J/cm^2
1000 μm	13 J/cm^2	32 J/cm^2	64 J/cm^2

Table 1: Relationship between laser beam diameter, energy per pulse, and resulting fluence values.

PAIN ASSOCIATED WITH BONE ABLATION

The classic tissue response to trauma such as surgery, as with infection, is inflammatory reaction. The five characteristics of *calor* (heat), *dolor* (pain), *rubor* (redness), *tumour* (swelling), and loss of function can result in postoperative oedema, pain, and trismus. It is considered that the level of kinin production following surgery plays a large part in the degree of pain and swelling. Anecdotally, the patient response following bone ablation with lasers appears to be one of greater comfort, compared to surgery carried out with a rotary bur. The number of investigations into this subject appears to be small. However, in a randomised controlled clinical trial,[25] the Er:YAG laser was compared with a surgical bur for removal of partially erupted lower third molars. Patients were allocated randomly to be treated by either laser or bur. A total of 42 patients (laser = 22; bur = 20) were treated. The study reported a greater reduction in the range of mouth opening after laser than after bur treatment, presumably due to the longer operating time taken although postoperative pain was more common after bur treatment.

CONCLUSION

The use of suitable laser wavelengths in the cutting and ablation of bone during dentoalveolar surgery can offer distinct advantages over rotary instrumentation. The reduction in heat production and thermal collateral damage can result in a less aggressive inflammatory process in the host tissue. In addition, the reduction in tactile stimulation during surgery can be deemed less unpleasant for the patient. To avoid damaging effects, there is only a narrow range of laser energy recommended for ablation of bone tissue. It is essential to use the correct laser wavelength and power parameters to maximise predictable outcomes for bone surgery in dentistry.

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-Recognised 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.*

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