AAP-Commissioned Review

Lasers in Periodontics: A Review of the Literature

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Background: Despite the large number of publications, there is still controversy among clinicians regarding the application of dental lasers to the treatment of chronic periodontitis. The purpose of this review is to analyze the peer-reviewed research literature to determine the state of the science concerning the application of lasers to common oral soft tissue problems, root surface detoxification, and the treatment of chronic periodontitis.

Methods: A comprehensive computer-based search combined the following databases into one search: Medline, Current Contents, and the Cumulated Index of Nursing and Allied Health. This search also used key words. In addition, hand searches were done for several journals not cataloged in the databases, and the reference lists from published articles were checked. All articles were considered individually to eliminate non-peer-reviewed articles, those dealing with commercial laser technology, and those considered by the author to be purely opinion articles, leaving 278 possible articles.

Results: There is a considerable conflict in results for both laboratory studies and clinical trials, even when using the same laser wavelength. A meaningful comparison between various clinical studies or between laser and conventional therapy is difficult at best and likely impossible at the present. Reasons for this dilemma are several, such as different laser wavelengths; wide variations in laser parameters; insufficient reporting of parameters that, in turn, does not allow calculation of energy density; differences in experimental design, lack of proper controls, and differences in severity of disease and treatment protocols; and measurement of different clinical endpoints.

Conclusions: Based on this review of the literature, there is a great need to develop an evidence-based approach to the use of lasers for the treatment of chronic periodontitis. Simply put, there is insufficient evidence to suggest that any specific wavelength of laser is superior to the traditional modalities of therapy. Current evidence does suggest that use of the Nd:YAG or Er:YAG wavelengths for treatment of chronic periodontitis may be equivalent to scaling and root planing (SRP) with respect to reduction in probing depth and subgingival bacterial populations. However, if gain in clinical attachment level is considered the gold standard for non-surgical periodontal therapy, then the evidence supporting laser-mediated periodontal treatment over traditional therapy is minimal at best. Lastly, there is limited evidence suggesting that lasers used in an adjunctive capacity to SRP may provide some additional benefit. *J Periodontol 2006;77:545-564.*

KEY WORDS

Bacteria; calculus; chronic periodontitis; lasers; periodontics; root.

Periodically, the Board of Trustees of the American Academy of Periodontology identifies the need for review of the literature on a specific topic and requests the Editor-in-Chief of the Journal of Periodontology *to commission such a review. The selected author is solely responsible for the content, and the manuscript is peer reviewed, like all other* Journal *articles. The Academy's Board of Trustees does not review or approve the manuscript prior to publication, and the content of the review should not be construed as Academy policy.*

Based on Albert Einstein's theory of spontaneous and stimulated emission of radiation, Maiman developed the first laser prototype in 1960.[1] Maiman's device used a crystal medium of ruby that emitted a coherent radiant light from the crystal when stimulated by energy. Thus, the ruby laser was created. Shortly thereafter, in 1961, Snitzer[2] published the prototype for the Nd:YAG laser. The first application of a laser to dental tissue was reported by Goldman et al.[3] and Stern and Sognnaes,[4] each article describing the effects of the ruby laser on enamel and dentin. However, the current relationship of

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doi: 10.1902/jop.2006.050417

dentistry with the laser takes its origins from an article published in 1985 by Myers and Myers[5] describing the in vivo removal of dental caries using a modified ophthalmic Nd:YAG laser.[4] Four years later, it was suggested that the Nd:YAG laser could be used for oral soft tissue surgery,[6] which ultimately lead to the present relationship between lasers and clinical periodontics.[7-9]

The subject of lasers in periodontics now encompasses a rapidly increasing and significant volume of published literature. Despite the large number of publications, there is still controversy among clinicians regarding the application of dental lasers to the treatment of periodontal diseases, and more specifically, chronic periodontitis. The purpose of this review is to analyze the peer-reviewed research literature to determine the state of the science regarding the application of lasers to common oral soft tissue problems, root surface detoxification, and the treatment of chronic periodontitis.

MATERIALS AND METHODS

The search to locate relevant articles for this review was undertaken at several levels. The first two searches were done with Medline-Ovid using an explode of "periodontal diseases" and an explode of "lasers." The result of this search was first limited to English only and randomized clinical trials, which resulted in 23 articles.

A comprehensive second search combined the following databases into one search: Medline, Current Contents, and the Cumulated Index of Nursing and Allied Health. This search combined the truncated search words: periodont$ or gingiv$, or mouth mucosa and laser$. Duplicates were removed, leaving 1,137 possible articles. This result was limited to English-only articles and the years 1990 to 2005, for a total of 906 articles. In addition, hand searches were done for the *Journal of Oral Laser Applications*, the proceedings of the Lasers in Dentistry conferences sponsored by the International Society for Optical Engineering (SPIE), and the Proceedings of the International Congress on Lasers in Dentistry. Lastly, the reference lists from published articles were checked. All articles were considered individually to eliminate non-peer-reviewed articles, those dealing with commercial laser technology, and articles considered by the author to be purely opinion articles, leaving 278 possible articles.

In compliance with the *Journal of Periodontology* instructions to authors, free-standing abstracts were not considered for inclusion in this review. From this final number of articles, the majority of those cited in this review were published since 1995. It should be noted that a few selected articles published as literature reviews or opinion articles or those concerned with the physics of laser-tissue interactions were used to present background material and to place comments by the present author in context.

Table 1 shows the results of the literature search by journal title. Table 2 displays the number of studies categorized by their experimental design. In order of decreasing clinical relevance, the experimental designs were as follows: randomized, blinded, controlled, longitudinal, clinical trials, cohort or longitudinal studies,

Table 1.

Results of the Computer-Based Literature Search by Journal Title for Articles on Lasers and Periodontics

Journal Name	Number of Published Articles (1990 to 2005)
Compendium of Continuing Dental Education	5
Dental Clinics of North America	13
Dental Economics	8
Dentistry Today	15
International Journal of Periodontics & Restorative Dentistry	3
Journal of the American Dental Association	3
Journal of Clinical Laser Medicine and Surgery	7
Journal of Clinical Periodontology	12
Journal of Dentistry	1
Journal of Dental Research	2
Journal of the International Academy of Periodontology	3
Journal of Oral Laser Applications	22
Journal of Periodontology	39
Journal of Periodontics and Esthetic Dentistry	1
Journal of Periodontal Research	5
Lasers in Dentistry: Proceedings of SPIE	25
Lasers in Surgery and Medicine	30
Periodontology 2000	2
Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology and Endodontics	2
Quintessence International	1
Miscellaneous	79
Total number of published articles	278

Table 2.

Number of Published Articles on Lasers in Periodontics Listed by Experimental Design in Order of Decreasing Clinical Relevance

Experimental Design	Number of Published Articles	Percentage of Total
Randomized, blinded, controlled, longitudinal, clinical trials	3	1.1
Cohort or longitudinal studies	20	7.2
Case-controlled studies	12	4.3
Non-controlled case studies	25	9.0
Descriptive studies	44	15.8
In vivo animal studies	27	9.7
In vitro laboratory studies	59	21.2
Reviews of the literature	88	31.7
Total number of articles	278	100.0

case-controlled studies, non-controlled case studies, descriptive studies, in vivo animal studies, and in vitro laboratory studies.[10] The category of literature review has been added for informational purposes.

Importance of Wavelength

Typically, lasers are named according to the active element(s) that is induced to undergo the stimulated quantum transitions that, in turn, creates the energy beam. Thus, lasers commonly used in dentistry consist of a variety of wavelengths delivered as either a continuous, pulsed (gated), or running pulse waveform, e.g., CO_2, Nd:YAG, Ho:YAG, Er:YAG, Er, Cr:YSGG, Nd:YAP, GaAs (diode), and argon (Table 3).

The following description pertains to those laser wavelengths and waveforms currently available to dentistry. Shorter wavelengths and pulse widths combined with higher-power densities as seen with some medical and industrial lasers bring with them other interaction phenomena that are not currently relevant to dental applications and, therefore, will not be discussed in this article.

The energy emitted by a laser is essentially a light of one color (i.e., monochromatic) and, therefore, of one wavelength. The photons comprising the energy beam are emitted as a coherent (in phase), unidirectional, monochromatic light that can be collimated into an intensely focused beam that exhibits little divergence. The focused energy beam will interact with a target material by being absorbed, reflected, or scattered. In the case of biologic tissues, the laser energy is absorbed by the target surface tissues and will only exhibit scattering in cases of deep tissue penetration. The absorbed light energy is converted to heat and constitutes a photothermal event. Depending on various parameters, the absorbed energy can result in simple warming, coagulation, or excision and incision through tissue vaporization. Variable parameters affecting energy absorption include emission wavelength, power (watts), waveform (continuous or pulsed), pulse duration, energy/pulse, energy density, duration of exposure, peak power of pulse, angulation of the energy delivery tip to the target surface, and optical properties of the tissue.

Although the wavelength of light is the primary variable that determines the extent of energy absorption by a target tissue, one must also be aware of the optical properties of the tissue. The optical properties of a tissue dictate, to a great extent, the interaction with specific laser wavelengths. For example, optical properties of tissues comprising the periodontium include such factors as pigmentation, water content, mineral content, heat capacity that accounts for both thermal conductivity and tissue density, and latent heats of transformation (i.e., denaturing of proteins, vaporization of water, and melting of mineral). Bone is considered the classic composite tissue, being comprised of ≈67% inorganic minerals (calcium hydroxyapatite) and 33% collagen and non-collagenous proteins. By contrast, gingiva is comprised of varying densities of fibrous connective tissue, associated extracellular matrix components, and a high content of water (≈70%). Additionally, the gingivae frequently exhibit melanin pigmentation. Other factors that likely play a role in laser-tissue interactions include the physiologic and mechanical processes of heat conduction and dissipation, the degree of tissue inflammation and vascularity, and the availability of progenitor cells to participate in the healing process.

Each wavelength of laser energy is absorbed to a greater or lesser degree in water, pigment, or hydroxyapatite. As examples, the CO_2 laser (10,600-nm wavelength) has a high absorption coefficient in water and consequently is well suited for soft tissue surgery but currently has no scientifically well-supported clinical application to mineralized tissues. The Nd:YAG (1,064-nm wavelength) and diode lasers (800- to 950-nm wavelength) have lower absorption coefficients in water than CO_2 lasers but are preferentially absorbed in pigmented tissues, and the Er,Cr:YSGG and Er:YAG wavelengths (2,780 and 2,940 nm, respectively) are highly absorbed in both water and hydroxyapatite. Given the diversity of available wavelengths, the prudent clinician should first determine the specific clinical treatment goals and then select the technology (laser or otherwise) best suited to achieve the desired endpoint(s).

Table 3.

Characteristics of Laser Wavelengths Used in Clinical Dentistry

Laser Type	Common Abbreviation	Wavelength	Waveform	Delivery Tip	Reported Periodontal Applications
Carbon dioxide	CO_2	10.6 µm	Gated or continuous	Hollow waveguide; beam focused when 1 to 2 mm from target surface	Soft tissue incision and ablation; subgingival curettage
Neodymium:yttrium-aluminum-garnet	Nd:YAG	1.064 µm	Pulsed	Flexible fiber optic system of varying diameters; surface contact required for most procedures	Soft tissue incision and ablation; subgingival curettage and bacterial elimination
Holmium:yttrium-aluminum-garnet	Ho:YAG	2.1 µm	Pulsed	Flexible fiber optic system; surface contact required for most procedures	Soft tissue incision and ablation; subgingival curettage and bacterial elimination
Erbium:yttrium-aluminum-garnet	Er:YAG	2.94 µm	Free-running pulsed	Flexible fiber optic system or hollow waveguide; surface contact required for most procedures	Soft tissue incision and ablation; subgingival curettage; scaling of root surfaces; osteoplasty and ostectomy
Erbium, chromium:yttrium-selenium-gallium-garnet	Er,Cr:YSGG	2.78 µm	Free-running pulsed	Sapphire crystal inserts of varying diameters; surface contact required for most procedures	Soft tissue incision and ablation; subgingival curettage; osteoplasty and ostectomy
Neodymium:yttrium-aluminum-perovskite	Nd:YAP	1,340 nm	Pulsed	Flexible fiber optic system; surface contact required for most procedures	Soft tissue incision and ablation; subgingival curettage and bacterial elimination
Indium-gallium-arsenide-phosphide; gallium-aluminum-arsenide; gallium-arsenide	InGaAsP (diode) GaAlAs (diode) GaAs (diode)	Diodes can range from 635 to 950 nm	Gated or continuous	Flexible fiber optic system; surface contact required for most procedures	Soft tissue incision and ablation; subgingival curettage and bacterial elimination
Argon	Ar	488 to 514 nm	Gated or continuous	Flexible fiber optic system	Soft tissue incision and ablation

Oral Soft Tissues

Clinical applications. For many intraoral soft tissue surgical procedures, the laser is a viable alternative to the scalpel. In this regard, the literature is replete with numerous case reports and uncontrolled case studies reporting the use of various laser wavelengths, primarily CO_2, Nd:YAG, and diode, for intraoral soft tissue procedures, such as frenectomy, gingivectomy and gingivoplasty, deepithelization of reflected periodontal flaps, removal of granulation tissue, second-stage exposure of dental implants, lesion ablation, incisional and excisional biopsies of both benign and malignant lesions, irradiation of aphthous ulcers, coagulation of free gingival graft donor sites, and gingival depigmentation.

Wound healing. The purported advantages of lasers versus scalpel surgery have been enumerated by numerous authors and include increased coagulation that yields a dry surgical field and better visualization; the ability to negotiate curvatures and folds within tissue contours; tissue surface sterilization and, therefore, reduction in bacteremia; decreased swelling, edema, and scarring; decreased pain; faster healing response; and increased patient acceptance.[11,12]

Clearly, some of the claimed advantages are common sense conclusions based on clinical observations and patient response; for example, coagulation leading to better visualization of the surgical field and increased patient acceptance. Surprisingly, there are little data to support other contentions, such as faster healing response or decreased scarring. Indeed, claims of faster healing of laser soft tissue wounds appear to be wavelength specific and highly sensitive to energy density.

Most studies that examined healing rates of laser-induced wounds have involved the CO_2, Nd:YAG, or diode wavelengths. Studies concerning the CO_2 laser report that soft tissue healing is slower overall,[13] slower initially but equal at 14 days,[14] or equivalent[15-17] compared to a conventional scalpel wound.

A comparison of wound healing following irradiation by the Nd:YAG and CO_2 lasers indicates that CO_2 laser–induced wounds in oral, oropharyngeal, and laryngeal mucosa healed significantly faster than those created by the Nd:YAG laser, but both heal slower than the conventional scalpel-induced wound.[13] Delayed healing of Nd:YAG laser wounds compared to scalpel incisions also has been reported by Romanos et al.[18] but only when using 3 W of power and a 20-Hz pulse rate. Healing was equivalent for scalpel and Nd:YAG wounds when the laser was used at a lower power setting of 1.75 W and 20 Hz.

Accelerated healing following laser-induced wounding has been reported but generally involves non-periodontal applications and use of soft lasers, e.g., low-level energy from a helium-neon diode.[19,20] However, even this contention has been challenged by Damante et al.[21] and Masse et al.,[22] both of whom reported no evidence of accelerated healing following gingivectomy or periodontal flap surgery, using 670- and 810-nm diode lasers, respectively. Indirect evidence of accelerated healing from low-energy laser irradiation is offered by Crespi et al.,[23] who used the CO_2 laser in a defocused mode following surgical flap exposure of experimentally induced furcation involvements and reported induction of new periodontal ligament, cementum, and bone in Class III furcations in a dog experimental model. Lastly, almost as a casual observation, several studies have reported that laser-induced wounds show a decreased tendency toward scar contraction compared to traditional scalpel surgeries.[24,25]

White et al.[26] used CO_2, Nd:YAG, Er:YAG, and two diode wavelengths (815 and 980 nm) to irradiate fresh bovine or porcine jaw tissue specimens. Based on tissue histology, it was determined that high power (watts), long pulse duration, high repetition rates (hertz), and long interaction times (duration of target exposure) all increased the risk of detrimental outcomes. In this regard, it should be noted that numerous articles have been published in medical and veterinary journals comparing various laser wavelengths to electrosurgery and scalpel with regard to incisional time, blood loss, swelling and edema, pain, and general wound healing. However, the observations and conclusions of these studies are of limited value to clinical dentistry as most used power settings that ranged from five to 12 times greater than those used for dental surgical procedures. Furthermore, unlike oral mucosa, the target tissues in most of these studies were generally dermis or muscle with distant proximity to underlying bone.

Oral Hard Tissues

Effect of lasers on bone healing. Regardless of the type of instrumentation, the healing of bone following ostectomy, osteoplasty, or implant site preparation is complex, involving both local and systemic responses and a variety of cell types, enzymes, growth factors, cytokines, and other types of signal proteins. Exposure of bone to heating at levels ≥47°C is reported to induce cellular damage leading to osseous resorption, and temperature levels of ≥60°C result in tissue necrosis.[27] Given that laser/biologic tissue interactions are photothermal events that, in turn, are wavelength dependent, it should not be surprising that with the possible exception of two wavelengths (Er:YAG and Er,Cr:YSGG) the effect of most dental lasers on bone is generally detrimental.

There are relatively few studies measuring real-time bone surface temperatures while the overlying soft tissues are being irradiated by a dental laser. One such study by Fontana et al.[28] examined temperature increases at the bone surface while using an 810-nm diode laser within periodontal pockets in rats. Following 9 seconds of irradiation using 800 mW, 1.0 W, and 1.2 W of power delivered through a 300-μm optical fiber, they reported 10°C and 11°C increases in bone surface temperature. Only at a 600-mW setting was the bone surface temperature below the threshold for induction of cellular damage. If exposure time was lowered to 3 seconds, all power selections resulted in temperature increases that stayed below the critical threshold.

A second study[29] compared, in vitro, the CO_2 and Nd:YAG lasers using comparable energy densities for their effects on bone surface temperature while ablating overlying soft tissues. Energy densities ranged from 688 to 1286 J/cm^2, and all test runs were executed both with and without air/water surface cooling. Results showed that bone surface temperature increases ranged from 1.4°C to 2.1°C for the CO_2 laser and from 8.0°C to 11.1°C for the Nd:YAG laser. Although this was an in vitro study, these results indicated that when ablating relatively thin soft tissues supported by subjacent bone (e.g., mandibular facial gingival and alveolar mucosa), the Nd:YAG laser should be used at low energy densities for short intervals; otherwise, there is a risk of irreversible bone damage.

Two studies have compared healing of tibial osteotomy defects in rats created by rotary bur, CO_2 (780 and 1,032 J/cm2) and Nd:YAG lasers (714 and 1,000 J/cm^2). At all time intervals (0 to 63 days post-treatment), regardless of energy density or use of air/water surface coolant during irradiation, the osseous healing response was severely delayed.[30,31]

Severe collateral damage has been identified as a major factor in delayed healing of laser-induced bone incisions. In studies reporting delayed healing, common observations appear to be the presence of a residual carbonized (char) layer on the treated surface, presence of inert bone fragments encapsulated by fibrous connective tissue, sequestra of bone, and bone fragments surrounded by multinucleated giant cells.[17,30]

Given the limited collateral damage and efficacy of the Er:YAG laser when cutting enamel and root surfaces, one would expect numerous similar studies using bone as the target tissue. However, there are only about nine studies dating back to the mid-1980s. Two of the more recent studies employed a variety of techniques to evaluate the Er:YAG laser used at multiple energy settings, pulses/second (hertz), pulse durations, and water surface coolant to prepare osteotomy defects in a rat experimental model. Osteotomies created by the Er:YAG laser were compared to those created by rotary bur and the CO_2 laser.[32,33] Collectively, the two studies indicate the Er:YAG laser, when used at a peak pulse energy of 100 mJ/pulse and 10 Hz, produced well-defined intrabony cuts with no evidence of melting or carbonization. Fourier transform infrared spectroscopy (FTIR), electron dispersive x-ray spectroscopy (EDX), and x-ray diffraction analysis revealed normal collagen/hydroxyapatite relationships covered by a thin surface layer characterized by a slight increase in calcium/phosphate ratio of the lased surface to be a result of formation of tetracalcium phosphate, which develops at temperatures above 1,100°C. Otherwise, the bone chemical composition was similar to that of defects produced by rotary bur. By contrast, CO_2 laser–induced osteotomies exhibited extensive charring, melting of the mineral phase, and delayed healing.

When considering laser-mediated osteotomy and/or ostectomy, the Er,Cr:YSGG appears to be a popular laser with clinicians. Yet, even with this wavelength, there is a paucity of evidence in the literature to support its use on bone. The clinical application of this wavelength to osseous resection and recontouring appears to be based on evidence derived from studies where the laser was used on enamel and dentin.

However, two recent studies suggest that the Er,Cr:YSGG wavelength may be suitable for use on bone. Kimura et al.[34] evaluated the morphological (scanning electron microscopy [SEM]), atomic (EDX), and temperature changes in canine mandibular bone, in vitro, following irradiation with the Er,Cr:YSGG laser at power settings of 5 W and 8-Hz pulse repetition for 10- or 30-second durations with concomitant air/water surface spray. The maximum temperature increase of 12.6°C was achieved only during the 30-second exposure. EDX analysis showed no change in calcium/phosphate ratio, and the SEM examination revealed cleanly cut bone with no evidence of charring or melting. Wang et al.[35] used the laser at an energy density of 80 J/cm^2 to create osseous perforations of 0.4-mm diameter in the maxilla and mandible of rabbits. They reported normal and complete healing of the wounds at 56 days post-treatment.

Laser-induced root surface modifications. Surface modification of cementum and dentin has been studied using a variety of laser wavelengths, primarily CO_2, Nd:YAG, Er:YAG, and, to a lesser extent, the diode laser.[36] A major conceptual consideration in laser-induced root surface modification is selection of a wavelength that will effectively remove calculus while suppressing both thermal damage to the pulp tissue and undesired removal of sound root structure. Achievement of these goals requires a wavelength characterized by minimal penetration depth in mineralized tissue. The mineral phase of both cementum and dentin is a carbonated hydroxyapatite that has intense absorption bands in the mid-infrared region. Consequently, of the laser wavelengths studied, the Er:YAG laser would appear to be the instrument of choice for effective removal of calculus, for root etching, and for creation of a biocompatible surface for cell or tissue reattachment. This latter statement is supported by Aoki et al.[36] in their definitive review of the literature concerning laser applications in nonsurgical periodontal therapy.

In chronological terms, the CO_2 laser appears to have been the first of the currently available wavelengths to be studied for effects on root surfaces. Even at power settings as low as 4 W, the results of the earlier studies were not particularly encouraging, in that charring and melting of the root surface were common findings. In addition, FTIR analysis of charred surfaces revealed the presence of cyanamide and cyanate, both cytotoxic chemical residues.[37]

More recent studies of the biocompatibility of CO_2 laser–treated surfaces, even when used at low energy densities, have yielded conflicting results. For example, both Pant et al.[38] and Crespi et al.[39] have reported increased in vitro attachment of fibroblasts to laser-treated surfaces compared to controls of SRP or chemically treated surfaces. On the other hand, Fayad et al.[40] reported a total lack of fibroblast attachment to surfaces irradiated at only 1.25 mJ/pulse.

Gopin et al.[41] used an in vivo animal model to demonstrate cytotoxicity of root surface char resulting from CO_2 laser irradiation subsequent to mucoperiosteal flap surgery. In all cases where root charring was observed, histologic examination revealed a lack of flap reattachment to the root surface. By contrast, all specimens treated by SRP alone or by laser irradiation followed by SRP exhibited flap reattachment to the treated root surfaces.

Heat-induced cracking of the root surface is a common observation when using the CO_2 laser, particularly at power settings of ≥4 W delivered in a continuous waveform. However, when used in a defocused mode, with pulsed waveform, and at low power settings, the CO_2 laser appears to inflict little damage.[42] Indeed, using such parameters, the CO_2 laser has been shown to effectively remove smear layers.[43] Despite the latter results, due to the diameter of the hollow delivery tip (≥1 mm) that is required to transmit the energy beam, CO_2 lasers have restricted application in subgingival periodontal therapy.

Studies concerning applications of the Nd:YAG laser to root surfaces, such as those concerning the CO_2 laser, have yielded mixed results. Israel et al.[44] compared root surface changes following irradiation with CO_2, Nd:YAG, and Er:YAG lasers. At energy densities of 100 to 400 J/cm^2 for the CO_2 and 286 to 1,857 J/cm^2 for the Nd:YAG lasers, the authors noted that the degree of morphologic change following laser irradiation was directly related to energy density but unrelated to use of an air/water surface coolant. Changes in root surfaces included cavitation defects, globules of melted and resolidified mineral, surface crazing, and production of a superficial char layer.

Several in vitro studies[36,45-47] have demonstrated heat-induced morphological changes of the root surface following irradiation with the Nd:YAG laser at power settings ranging from a low of 156.2 to 166.6 J/cm^2 to a high of 571 J/cm^2. As with the CO_2 laser, the Nd:YAG laser produced root surface alterations that included craters, charring, and melting and resolidification of the mineral phase. It should be noted, however, that even the lowest energy density used in these studies was still greater than those currently recommended for in vivo use. At least one study has reported altered chemical organization of root structure proteins following irradiation with the Nd:YAG laser at relatively low power settings (0.5 to 1.5 W).[48] Such heat-induced alterations in root structure proteins undoubtedly account for the separation of cementum from dentin following Nd:YAG irradiation and SRP, in vitro, reported by Morlock et al.[49]

A recent study by Chen et al.,[50] in which cell cultures of human periodontal ligament fibroblasts were subjected to Nd:YAG irradiation at low energy densities, reported significant decreases in cellular viability and collagen synthesis at 5 days post-treatment and evidence of mineralization of necrotic cells at 28 days post-treatment. Laser parameters were 50 mJ of power and 10 Hz, with a defocused beam delivered through a 400-μm-diameter optical fiber, and durations of exposure ranging from 60 to 240 seconds.

In contrast with studies reporting detrimental results, at least two in vitro studies have demonstrated that the Nd:YAG laser, when used at low energy densities or a combination of low energy density with a defocused beam, can remove root surface smear layers without causing collateral damage to underlying cementum and/or dentin or increasing temperatures to a level that might trigger irreversible pulpal damage.[51,52]

Two studies with similar experimental designs and diametric results demonstrate the possible effect that differing laser wavelengths can have on cells in vitro. The first study, using GaAs and GaAlAs diode lasers at energy densities between 0.95 and 6.32 J/cm^2, evaluated the effect of laser irradiation on prostaglandin E_2 (PGE_2) production and cyclooxygenase-1 (COX-1) and COX-2 gene expression in lipopolysaccharide-challenged human gingival fibroblasts.[53] The authors reported that irradiation with the GaAlAs diode laser significantly inhibited PGE_2 production in a dose-dependent manner, which, in turn, lead to reduction of COX-2 mRNA levels. The second study irradiated cell cultures of human gingival fibroblasts with an Er:YAG laser at energy densities ranging from 1.68 to 3.37 J/cm^2 and actually increased production of PGE_2 and COX-2 mRNA.[54]

Other in vitro studies have reported a lack of positive effect on attachment of periodontal ligament cells to root surfaces following low-level irradiation (1 W for 20 seconds) with the GaAlAs diode laser[55] or detrimental ultrastructural changes that could potentially lead to disturbances in collagen synthesis.[56] Despite these reports, Kreisler et al.[57] reported that low-level irradiation with the GaAlAs diode laser (10 mW for 75, 150, and 300 seconds) had a stimulatory effect on the proliferation of periodontal ligament fibroblasts in vitro. Given the findings of these studies, one might conclude that differing levels of power and times of exposure produce different interactive results that, in turn, indicate an irradiation threshold above which cell damage is likely to occur.

Another example of the importance of parameter selection was reported by Kreisler et al.[58] following in vitro irradiation of tooth root specimens with the GaAlAs diode. The study reported little to no damage on the root surface at a power output of ≤1 W, whereas power selections of 1.5, 2.0, and 2.5 W produced varying degrees of carbonization (charring) and heat-induced surface cracking.

Due to its high absorption in both water and hydroxyapatite, the bulk of recent research concerning laser-induced root surface modification has involved the Er:YAG laser. This wavelength of laser has been shown to effectively remove smear layers,[44,59] dental calculus,[60-63] cementum,[61,64] and cementum-bound endotoxin.[65] When used at low energy densities with a water spray surface coolant, the majority of studies report little to no heat-induced tissue damage and production of smooth root surfaces.[65,66] In addition, in vitro fibroblast adhesion studies show that the resultant root surface appears to be at least as biocompatible as that produced by SRP.[60,67,68]

There are, however, caveats with respect to the Er:YAG laser and root surface interactions. First, the water spray surface coolant appears important in suppressing heat-induced surface alterations and protection of the pulp against elevations in temperatures during root surface irradiation.[63,64,66,69] Achievement of adequate water cooling in deeper periodontal pockets is likely to be inconsistent. Second, most studies reporting heat-induced surface damage or lack thereof have used SEM. Obviously, the SEM is a surface-scanning microscope and does not detect subsurface damage. At least one study has noted subsurface alterations in dentin following ablation of cementum by the Er:YAG laser using power settings of 60, 100, and 180 mJ. The thermal changes extended into the dentin from 255 to 611 μm, as measured from the target surface, and appeared independent of irradiation energy.[70] Third, as with other laser wavelengths, the selection of parameters is of paramount importance when discussing tissue damage. In this regard, Crespi et al.[71] in an in vitro study noted that use of the Er:YAG laser in a defocused non-contact mode effectively removed calculus with only minimal removal of cementum. Several studies emphasize the relationship between increasing power and energy density and increased removal of root surface structure[63,64] and the number and depth of craters in the target surface.[61,64]

A relatively new laser, the Nd:YAP with a wavelength of 1,340 nm, has been tested on the root surfaces of extracted teeth. The authors reported the presence of heat-induced damage at energy densities ranging from 509 to 1,274 J/cm^2. However, as might be expected, the degree of damage was directly related to increasing energy density and progressively evolved from simple surface cracking of cementum to deep cratering to melting and deep ablation of cementum with exposure of the underlying dentin.[72]

Use of lasers for clinical crown lengthening without gingival flap reflection. Recently, the Er,Cr:YSGG laser, and to a lesser extent the Er:YAG laser, has been promoted for clinical crown lengthening without gingival flap reflection for both esthetic and prosthetic reasons.[73-78] These articles generally fall into one of two categories: non-controlled case studies and technique-oriented articles. Collectively, the articles raise several questions: 1) Is there sufficient tactile sensation transmitted through the laser delivery tip to allow the clinician to adequately distinguish between bone and root surface cementum and/or dentin? 2) Have any of these reports determined if the roots of treated teeth incur surface damage, e.g., cratering, ditching, charring, heat-induced cracking, or melting? 3) In cases requiring bone removal, does the lack of direct visualization allow the clinician to establish proper anatomical dimensions and contours that will maintain the gingival papilla post-surgically and prevent violation of the biologic width?

Currently, there are no controlled longitudinal or cohort studies supporting use of lasers for clinical crown lengthening using the closed-flap technique. Thus, there are no satisfactory answers to any of these questions because there are no published research data. The only existing support for such applications are non-controlled case reports. Obviously, esthetic crown lengthening can easily be managed with lasers if clinically short crowns are the result of gingival overgrowth or lack of passive eruption. However, in such cases, there is increased probing depth (PD) due to excessive amounts of soft tissue, and violation of the biologic width is usually not a major concern.

Effect of lasers on bacteria and calculus. The use of a dental laser in the treatment of chronic periodontitis is based on the purported benefits of subgingival curettage, laser-induced new attachment through regeneration of cementum, periodontal ligament, and supporting alveolar bone, and significant decreases in subgingival pathogenic bacteria. There is limited evidence suggesting that lasers effect greater reductions in subgingival bacteria than that achieved by traditional therapy. Indeed, most laser bactericidal studies have been in vitro investigations that have little relevance to the protected biofilms of a periodontal pocket. Indeed, regarding subgingival biofilms, such factors as thickness of microbial mass, density and thickness of extracellular matrix, microbial composition, color, and water content have yet to be replicated in vitro. Most laser bactericidal studies report a dose/response relationship; that is, increases in power or energy density result in increased destruction of bacteria. However, in many studies, energy densities are often not reported or cannot be calculated due to incomplete listing of parameters. Studies also vary in how the laser energy is delivered to the target surface, some using a sweeping motion of the delivery tip and others using a static exposure of single or multiple pulses. Lastly, the angle of irradiation can vary from 0 to 90°, making computation of energy densities nearly impossible. Despite these problems, one can still discern trends in the literature regarding the bactericidal effects of dental lasers.

One of the first in vivo studies reporting reductions in pathogenic bacteria following irradiation with the Nd:YAG laser showed decreases in *Porphyromonas gingivalis* (*Pg*), *Prevotella intermedia* (*Pi*), and *Actinobacillus actinomycetemcomitans* (*Aa*). However, teeth extracted 7 days post-treatment exhibited recolonization of laser-irradiated subgingival root surfaces by multiple morphotypes of bacteria.[79]

A later study,[80] also using the Nd:YAG laser, compared laser therapy to SRP and reported that both modalities reduced levels of *Tannerella forsythensis* (*Tf*), *Pg*, and *Treponema denticola* (*Td*) but incompletely eliminated *Aa*. Laser therapy resulted in a greater reduction in microbial levels than did SRP, although both treatments exhibited microbial rebound approaching baseline levels at 10 weeks post-therapy.

A third in vivo study compared SRP (one episode) to SRP followed by irradiation with the Nd:YAG laser at a relatively high energy density of 124 J/cm^2. Treated pockets were irradiated once per week for 3 weeks. Levels of *Pg*, *Pi*, and *Aa* were determined at 6 months post-treatment, and only levels of *Pg* were found to be significantly reduced compared to SRP.[81]

In vitro studies using the Nd:YAG laser at low power settings have reported calculus ablation without detrimental effects to underlying cementum or dentin;[82] a linear relationship between energy level, microbial numbers, and concentration of hemoglobin (blood) and minimal energy required for a bactericidal effect;[83] a differential susceptibility of various microbes to laser energy;[83] and a differential susceptibility to damage of calculus, cementum, and dentin, even within the same specimen.[82] The latter phenomenon is likely the result of such factors as variability in color, thickness, composition, texture, and water content.

There are relatively few articles regarding diode lasers and their respective interactions with bacteria and dental calculus. A well-designed study by Harris and Yessik[84] determined the in vitro ablation threshold for *Pg* for both the 810-nm diode and Nd:YAG lasers to be 48 and 96 J/cm^2, respectively. The diode laser (805 nm), when used adjunctively with SRP, has been shown to have an additive effect in reducing subgingival bacterial populations in periodontal pockets of ≥4 mm in depth.[85] Interestingly, the diode laser used at low intensity (1 J/cm^2) has also been shown to have an in vitro stimulatory effect on bacterial growth that appears to be species specific.[86]

Coffelt et al.[87] demonstrated in vitro bacterial ablation with the CO$_2$ laser in a defocused mode at an energy density of 11 J/cm^2. They also determined the threshold energy density for inducing root damage to be 41 J/cm^2, well above that required to destroy bacteria adherent to a root surface. Following this line of thought, Crespi et al.[88] demonstrated that the use of SRP followed by CO$_2$ laser irradiation at an energy density of 2.45 J/cm^2 produced root surfaces devoid of residual bacteria. One caveat, however, is that ablation of bacteria requires a direct hit by the energy beam. There appears to be a well-defined interface between irradiated bacteria and those not damaged by the energy beam.[89] This factor may explain why many in vivo studies show the persistence of viable bacteria following subgingival laser irradiation.

As with other wavelengths, studies involving the Er:YAG laser are predominantly in vitro investigations. Collectively, these studies report bacterial ablation at energy densities as low as 0.3 J/cm^2,[90] effective removal of calculus without associated heat-related damage to the root structure at energy densities of ≤10.6 J/cm^2,[91,92] and removal of root structure without significant increases in pulp chamber temperatures.[91]

By contrast, Aoki et al.[93] reported an equivalent effect when using ultrasonic instrumentation or the Er:YAG laser at an energy density of 14.2 J/cm^2 for the in vitro removal of calculus from extracted teeth. The laser produced slightly rougher topography and thermal microchanges on the root surface. Folwaczny et al.[94] offer another caveat, in that in vitro use of the Er:YAG laser (60 mJ, 15 Hz, 250-microsecond pulse duration, and a total of 55, 75, or 105 pulses) on root surfaces seeded with bacteria only reduced bacterial loads by one log. Lastly, Eberhard et al.[95] compared laser removal of calculus to SRP in situ. Microbial samples were taken prior to and immediately after treatment for DNA probe analysis. Following tooth extraction, SEM using digitized planimetry was used to measure residual calculus. Results showed that only 68.4% of the root surface was calculus free in contrast to 94% after SRP. If the laser was used for twice the time as that for SRP, the percentage of root surface devoid of calculus increased to 83.3%. Both treatments resulted in similar reductions of pathogenic microbes.

Treatment of Chronic Periodontitis

As previously stated, laser-mediated periodontal therapy is predicated on the concept of subgingival curettage and/or reattachment and regeneration of the attachment apparatus. Such laser therapy is commonly referred to as "non-surgical." Clearly, use of the term non-surgical when referring to a procedure based on the concept of subgingival curettage is debatable. Be that as it may, there are no convincing data that a regenerated connective tissue attachment is superior to attachment via a long-junctional epithelium, the latter commonly a result of non-surgical mechanical therapy.[96,97] The desirability of the connective tissue attachment is based on hypothesis, not fact. Indeed, at least two investigations report that attachment mediated by long-junctional epithelium may

Table 4.

Laser Treatment of Chronic Periodontitis: Summary of Longitudinal Clinical Trials and Cohort Studies

Study (listed in chronological sequence)	Type of Laser	Number of Patients	Length of Study (days)	Initial PD (mm)	Decrease in Subgingival Bacteria: Laser Versus Control
Rydėn et al.[112]	GaAs diode	10	28	NA (gingivitis study)	No statistical difference between treatment groups.
Finkbeiner[116]	Argon	30	138	4 to 5 6 to 7 8 to 9	NA
Ben Hatit et al.[80]	Nd:YAG	14	70	≥5	No significant difference. Reported reductions in *Tf*, *Pg*, and *Td* but not *Aa*. All microbes rebounded to baseline at 10 weeks.
Radvar et al.[117]	Nd:YAG	11	42	>4	At 6 weeks, only the SRP group showed a significant reduction from baseline.
Neill and Mellonig[101]	Nd:YAG	10	180	>4	No significant difference for *Pg* or *Pi*.
Moritz et al.[115]	GaAs diode	50	180	3.9 versus 3.0 (mean depth in molar region)	No significant difference. 59% of lased sites had 1 log decrease versus 33% of controls; 27% of lased sites had 2 log decrease versus 17% of controls.
Liu et al.[118]	Nd:YAG	8	84	4 to 6	NA
Schwarz et al.[103]	Er:YAG	20	180	≥4	No significant difference between treatment groups.
Gutknecht et al.[81]	Nd:YAG	20	175	4 to 6	No significant difference between treatment groups.

Table 4. (continued)

Laser Treatment of Chronic Periodontitis: Summary of Longitudinal Clinical Trials and Cohort Studies

Mean Reduction in PD: Laser Versus Control (mm)	Mean Gain in CAL: Laser Versus Control (mm)	Percentage of Decrease in BOP: Laser Versus Control	Comments
NA	NA	No statistical difference between test and controls.	Total dose of 1 J/cm^2 over 4 minutes; laser did not influence the inflammatory reaction of the marginal gingival in an experimental human gingivitis model. Controls were untreated.
1.62 versus NA 2.85 versus NA 3.30 versus NA	NA	75% versus NA	Used 0.4 W and 0.3-mm-diameter optical fiber with a 20- to 30-second exposure; no control group.
NA	NA	NA	Treatment groups: 0.8 W at 10 Hz and 100 mJ/pulse versus 1.0 W at 10 Hz and 100 mJ/pulse versus 1.2 W at 12 Hz and 100 mJ/pulse versus 1.5 W at 15 Hz and 100 mJ/pulse versus scaling only (control); pulse duration was 150 microseconds, and laser was fitted with 0.3-mm-diameter optical fiber.
0.50 versus 1.70	NA	<10% versus 45%	Treatment groups: 50 mJ versus 80 mJ (test) versus SRP (control); pulse duration of 150 microseconds using a 0.32-mm-diameter optical fiber; energy densities were 62.9 and 99.5 J/cm^2.
1.70 versus 0.50	1.1 versus 1.0	Significant difference but no data presented.	Treatment groups: SRP alone versus laser + SRP versus untreated control; 80 mJ at 25 Hz for 2 minutes; <4-mm pocket lased for 5 to 10 seconds; 4 to 6 mm lased for 20 seconds; 7 to 9 mm lased for 30 seconds; and >9 mm lased for 40 seconds.
1.30 versus 0.40	NA	Study used papillary bleeding index: improvement in 97% of lased versus 67% of controls.	Used 2.5 W and 50 Hz, and 10-microsecond pulse duration; controls were scaling followed by H_2O_2 rinsing at 1 week and at 2 and 4 months. Tests were scaled plus lased at 1 week and at 2 and 4 months.
NA	NA	NA	Laser versus SRP versus laser + SRP versus SRP + laser; 150 mJ at 20 pulses per second; determined that SRP was required to reduce levels of gingival crevicular fluid interleukin-1β.
2.00 versus 1.60	1.9 versus 1.0	77% versus 56%	Laser used at 160 mJ/pulse at 10 Hz (test) versus SRP (control).
0.85 versus 0.80 (estimated from line graph)	NA	85% versus 75% (estimated from line graph)	Used 100 mJ and 20 Hz, 100-microsecond pulse duration, 0.32-mm-diameter optical fiber, and energy density of 124 J/cm^2 at fiber tip. Control was untreated versus one-time SRP versus SRP + laser treatment of pocket once per week for 3 weeks. Measured levels of *Pg*, *Pi*, and *Aa*. Found no significant difference for *Pi* and *Aa*; difference for *Pg* was significant.

Table 4. (continued)

Laser Treatment of Chronic Periodontitis: Summary of Longitudinal Clinical Trials and Cohort Studies

Study (listed in chronological sequence)	Type of Laser	Number of Patients	Length of Study (days)	Initial PD (mm)	Decrease in Subgingival Bacteria: Laser Versus Control
Sjöstrom and Friskopp[119]	Nd:YCG (1,061 nm versus 1,064 nm for Nd:YAG)	27	120	≥4	NA
Yilmaz et al.[113]	GaAs diode	10	32	4	No significant difference between treatment groups.
Miyazaki et al.[102]	Nd:YAG	18	84	≥5	NA
Schwarz et al.[104]	Er:YAG	20	365	≥4	No significant difference between treatment groups.
Schwarz et al.[105]	Er:YAG	20	2 years	≥4	No significant difference between treatment groups.
Borrajo et al.[100]	InGaAsP diode	30	42	NA	NA
El Yazami et al.[109]	Nd:YAP	22	180	5.5 test, 5.2 control	NA
Harris et al.[120]	Nd:YAG	75*	180	4 to 6 7 to 9	NA
Sculean et al.[106]	Er:YAG	20	180	≥4	NA
Schwarz et al.[107]	Er:YAG	22	180	8.6	NA
Sculean et al.[108]	Er:YAG	23	180	7.8	NA
Ambrosini et al.[110]	Nd:YAP	30	90	4.1	No significant difference between treatment groups.

Table 4. (continued)

Laser Treatment of Chronic Periodontitis: Summary of Longitudinal Clinical Trials and Cohort Studies

Mean Reduction in PD: Laser Versus Control (mm)	Mean Gain in CAL: Laser Versus Control (mm)	Percentage of Decrease in BOP: Laser Versus Control	Comments
1.4 versus 1.4	NA	Gingival bleeding index showed no difference between treatment groups.	Treatment groups: laser + SRP + laser (test) versus SRP only (control); laser used at 7 W and 20 Hz with pulse length of 250 microseconds.
0.23 for laser only; 0.49 for SRP only; 0.66 for laser + SRP	NA	17% for laser only; 50% for SRP only; 60% for laser + SRP	Treatment groups: laser only versus laser + SRP versus SRP alone versus oral hygiene instructions alone; laser used at power density of 1.6 J/cm^2 on days 1, 2, 4, 7, 9, and 11 using methylene blue dye as a photosensitizer.
1.43 for Nd:YAG; 1.36 for scaling; 1.00 for CO$_2$	0.50 for Nd:YAG; 0.57 for scaling; 0.31 for CO$_2$	43% for Nd:YAG; 34% for scaling; 16% for CO$_2$	Treatment groups: Nd:YAG laser alone versus CO$_2$ alone versus ultrasonic scaling alone; Nd:YAG laser used at 100 mJ/pulse and 20 Hz for 2 minutes; CO$_2$ laser used at 2 W for 2 minutes.
2.0 for laser + SRP; 1.7 for laser only	Both treatments had 1.6-mm gains in CAL.	14% for laser + SRP; 16% for laser only	Treatment groups: laser + SRP (test) versus laser only (control); laser used at 160 mJ/pulse at 10 Hz.
1.60 versus 1.30	1.40 versus 0.70	64.3% versus 46.2%	Laser used at 160 mJ/pulse at 10 Hz versus SRP; this article reports the long-term results of the Schwarz et al.[103] study.
NA	0.81 versus 0.85	72% versus 53%	SRP versus SRP + laser; 2 W, 100-millisecond pulse length, 50 Hz, 2-mm-diameter optical fiber.
2.80 versus 1.30	2.60 versus 1.10	67.1% versus 51.2%	70 mJ and 30 Hz; SRP (control) versus SRP + laser (test).
1.55 versus NA 3.44 versus NA	NA	NA	Laser power ranged from 3.0 to 4.8 W depending on operator; 1 minute/tooth exposure delivered a total energy of 1 to 15 J/mm of PD. LANAP protocol. Study also includes data from the Neill and Mellonig[101] study. Controls were historic, i.e., compared to other studies.
1.52 versus 1.57	1.11 versus 1.11	23% versus 31%	Laser used at 160 mJ/pulse and 10 Hz (test) versus ultrasonic scaling (control).
4.00 versus 4.1	3.2 versus 3.3	35% versus 26%	Access flap surgery + laser debridement + enamel matrix protein derivative (test) versus access flap surgery + SRP + enamel matrix protein derivative (control); laser used at 160 mJ/pulse and 10 Hz.
3.7 versus 3.2	2.6 versus 1.5	62.5% versus 59%	Laser used at 160 mJ/pulse and 10 Hz (test) versus flap surgery and debridement of root and defect (control).
1.50 versus 1.30	1.00 versus 1.10	85.7% versus 85.7%	SRP only (control) versus SRP + laser (testy); bacteria tested by DNA probe: *Aa*, *Pi*, *Pg*, *Tf*, and *Td*; laser parameters were 10 W and 0.2-mm-diameter optical fiber.

Table 4. (continued)

Laser Treatment of Chronic Periodontitis: Summary of Longitudinal Clinical Trials and Cohort Studies

Study (listed in chronological sequence)	Type of Laser	Number of Patients	Length of Study (days)	Initial PD (mm)	Decrease in Subgingival Bacteria: Laser Versus Control
Noguchi et al.[111]	Nd:YAG	16	90	5.8 for control; 4.9 for laser; 5.2 for laser + minocycline; 5.4 for laser + irrigation	Proportions of *Pg*, *Pi*, and *Tf* were significantly decreased in laser + minocycline group compared to laser only and laser + irrigation groups.
Qadri et al.[114]	InGaAlP and GaAlAs diodes	17	42	4.7	No significant difference between treatment groups.

NA = not applicable because study did not measure parameter.
* Includes 10 patients from Neill and Mellonig[101] study.

be as resistant to disease as a true connective tissue attachment.[98,99]

A meaningful comparison between various clinical studies or between laser and conventional therapy is difficult at best and likely impossible at the present. Reasons for this dilemma are several, such as different laser wavelengths; wide variations in laser parameters; insufficient reporting of parameters that, in turn, does not allow calculation of energy density; differences in experimental design; lack of proper controls; differences in severity of disease and treatment protocol; and measurement of different clinical endpoints. Despite these problems and given that, to date, only 23 human clinical trials have been published,[80,81,100-120] one may still extract sufficient data to recognize trends in the results of laser-mediated treatment of chronic periodontitis (Table 4).

When measuring outcomes of non-surgical periodontal therapy, gain in clinical attachment level (CAL) represents the gold standard. PD and levels of subgingival microbes are important primarily because, in cases of traditional non-surgical mechanical therapy, they have been shown to be associated with changes in CAL.[10] Thus, it is somewhat surprising that only 12 of the 23 laser clinical trials considered gains in CAL as an endpoint of treatment (Table 4). If one calculates the average gain in CAL reported in 11[100-110] of the 12 studies for laser therapy versus controls (1.62 mm versus 1.26 mm, respectively), it becomes evident that there is minimal benefit following subgingival laser therapy. One study[111] was not included due to use of local drug delivery combined with laser therapy and lack of an SRP control group. Further analysis of these data shows that seven of the studies[100-102,104,106,107,110] reported essentially equivalent results between laser-treated groups and controls, and four studies[103,105,106,109] clearly favored laser therapy (average gain of 2.13 mm in CAL following laser therapy versus 1.05 mm for controls). Of the latter four studies, three involved the Er:YAG laser[103,105,108] and one the Nd:YAP laser,[109] and control groups consisted of SRP (three studies) and surgical flap with debridement (one study).[107]

There are presently five peer-reviewed published clinical trials using a diode laser wavelength. Two of these are actually an investigation of the effects of low-level laser therapy (LLLT) on the gingival inflammatory response in a human experimental gingivitis model.[99,111] Results showed that LLLT had no impact on bacterial plaque accumulation, bleeding on probing (BOP), or the number of vessels in the marginal gingiva, all being indicators of the inflammatory response.

Of the three remaining studies, three essentially reported little to no effect on bacterial levels[113-115] compared to controls and minimal changes in both PDs[113,114] and BOP.[96,109] Only one article has reported

Table 4. (continued)

Laser Treatment of Chronic Periodontitis: Summary of Longitudinal Clinical Trials and Cohort Studies

Mean Reduction in PD: Laser Versus Control (mm)	Mean Gain in CAL: Laser Versus Control (mm)	Percentage of Decrease in BOP: Laser Versus Control	Comments
1.57 for laser; 2.39 for laser + minocycline; 1.60 for laser + irrigation; no change for control	1.52 for laser; 2.36 for laser + minocycline; 1.62 for laser + irrigation; no change for control	63% for laser; 77% for laser + minocycline; 65% for laser + irrigation; 19% for control	Used 200 mJ and 10 Hz for 90 seconds with 0.4-mm-diameter optical fiber; treatment groups were laser only, laser + local minocycline, laser + povidone-iodine irrigation, and sham procedure (control). Each treatment was done every week for 1 month.
0.90 versus 0.20	NA	NA	First used InGaAlP laser with energy density of 4.5 J/cm^2 and then the GaAlAs laser in pockets ≥6 mm at energy density of 8.75 J/cm^2. Control was laser placebo (sham treatment with laser inactivated); measured levels of gingival crevicular fluid elastase, interleukin-1β, and matrix metalloproteinase-8 and found no significant differences resulting from laser treatment.

NA = not applicable because study did not measure parameter.
* Includes 10 patients from Neill and Mellonig[101] study.

significant effects on clinical parameters that favored the diode laser wavelength.[115] However, this study used inappropriate controls for comparison, i.e., both test and control patients received scaling of periodontally diseased sites, but sites in test patients were repeatedly lased at 1 week and 2 and 4 months, while control patients received no further treatment except to rinse with H_2O_2.

Finkbeiner[116] in an uncontrolled cohort study reported the effects of treating chronic periodontitis using an argon laser combined with subgingival scaling and chlorhexidine irrigation. Results showed reductions of 1.62, 2.85, and 3.30 mm for 4- to 5-, 6- to 7-, and 8- to 9-mm initial PDs, respectively. In addition, a 75% decrease in BOP was noted.

At present, there are only nine published clinical trials using the Nd:YAG laser for treatment of chronic periodontitis. When viewed as a collective body of evidence, they provide conflicting results.[80,81,101,102,111,117-119] For example, two studies did not measure PD as an endpoint,[80,118] three studies reported little to no difference in PD reduction when comparing laser-treated sites to control sites (SRP only),[81,102,109] and one study reported a greater mean decrease in PD in SRP-treated sites than in those treated by laser.[117] Of the remaining three studies, the laser improved PD compared to untreated controls[101] or historic controls (i.e., data reported in other studies used for comparison).[120] However, the study using historic controls[120] reported relatively large standard deviations for mean PD reductions in laser-treated pockets, indicating a variation in technique or a degree of unpredictability. Lastly, when the Nd:YAG laser was combined with locally delivered minocycline, PD was significantly reduced compared to sites treated by laser alone.[111]

In this same series of studies, results for BOP and reduction of pathogenic bacteria followed the same general trend as PD reduction. Take, for example, reductions in specific periodontal pathogens: four studies did not measure this factor as an endpoint,[102,118-120] two studies reported no difference between test and control groups in levels of subgingival bacteria,[81,101] one study reported that SRP was more effective than laser therapy,[117] and two studies reported significant decreases in laser-treated sites of *Tf*, *Td*, *Pg*, or *Pi*.[80,111] Interestingly, one study reported significant decreases in subgingival bacterial levels for both Nd:YAG laser–treated sites and SRP, but there was no difference between treatment groups in levels of *Pg* or *Pi*.[101] Lastly, one study reported that SRP was necessary to effect significant decreases in gingival crevicular fluid levels of interleukin-1β compared to laser only or combinations of laser and SRP.[118]

In general, clinical trials involving the Er:YAG laser in the treatment of chronic periodontitis are better designed and yield more consistent results. A major reason for this distinction is likely related to the fact that all six clinical trials have come from the same group of investigators.[103-108] Four of the six studies compared the effects of the Er:YAG laser alone or in combination with SRP to SRP alone.[103-106] The remaining two studies combined the laser with periodontal surgery or enamel matrix protein in the treatment of intrabony defects.[107,108]

With respect to reductions in subgingival bacterial loads, comparisons of Er:YAG laser therapy (alone or as an adjunct to SRP) to SRP alone were reported to have no significant difference between treatments, i.e., both groups showed a significant increase in cocci and non-motile rods and a decrease in the numbers of motile rods and spirochetes.[103-105] Decreases in mean PD consistently favored the laser treatment, but differences between treatment groups ranged from essentially no difference[107,108] to 0.4 at 6 months[98] and 1 year[105] to 0.3 mm at 1 year[104] and 2 years post-treatment.[105] Lastly, percentage of reduction in BOP in these studies was somewhat conflicted in that three studies favored the laser versus SRP,[103,105,107] two studies reported essentially equivalent reductions in BOP (14% versus 16% for laser + SRP versus laser alone[104] and 62.5% versus 59% for flap surgery + laser versus flap surgery + traditional debridement),[108] and one study favored SRP alone versus laser alone.[106] None of the BOP comparisons were reported as statistically significant differences.

A relatively new laser wavelength to dentistry is Nd:YAP (1,340 nm), which has an absorption coefficient in water approximately 20 times greater than the Nd:YAG laser (1,060 nm). Thus far, only two clinical trials using this laser in the treatment of chronic periodontitis have been published,[109,110] both comparing SRP + laser to SRP alone.

One study[109] reported a 1.5-mm mean difference in PD reduction (initial mean PD $\approx$5.5 mm) that favored adjunctive use of the laser with SRP versus SRP alone. In addition, there was a reported difference in reduction of BOP between the two treatment groups of 15%, again favoring the combined treatment protocol. The second study[110] measured plaque index, gingival index, BOP, PD, CALs, and the presence of *Aa*, *Pg*, *Pi*, *Tf*, and *Td*. The authors reported no significant difference between treatment groups for any of the measured clinical parameters, i.e., no additional advantage was achieved by using the Nd:YAP laser.

Examination of all 23 clinical trials reveals that blinded examiners were reported as part of the experimental design in only four of the studies,[100,104,109,110] and calibration of examiners was reported in six studies.[104-109] Such oversights in experimental design raise the issue of introducing bias when reporting experimental results. It is well accepted that the ultimate applicability and strength of recommendation for a specific treatment modality must be based on the weight of evidence. In this regard, a single randomized, blinded, controlled, longitudinal, clinical trial carries more weight than even a large series of case observations because of the greater potential for bias when observations are made under uncontrolled conditions. Although the dental literature is replete with clinical observations that have evolved from private practice settings, such studies rarely present concurrent controls; therefore, effectiveness of treatment is likely to be overestimated.

CONCLUSIONS

The results achieved following irradiation of biologic tissue by a specific wavelength of laser is directly related to the selected parameters. In other words, given the same wavelength, different laser parameters will yield different levels of energy density for varying periods of time and, thereby, different degrees of change in the target tissue. This review consistently noted that even when using the same wavelength of laser, there was little concurrence in the choice of parameters in the experimental methods. This recurring problem makes comparison of results nearly impossible and undoubtedly accounts for many of the reported conflicts in results for the various laboratory studies and clinical trials.

Based on this review of the literature, one must conclude that there is a great need to develop an evidence-based approach to the use of lasers for the treatment of chronic periodontitis. Simply put, there is insufficient evidence to suggest that any specific wavelength of laser is superior to the traditional modalities of therapy. Current evidence does suggest that use of the Nd:YAG or Er:YAG wavelengths for treatment of chronic periodontitis may be equivalent to SRP with respect to reduction in PD and subgingival bacterial populations. However, if gain in CAL is considered the gold standard for non-surgical periodontal therapy, then the evidence supporting laser-mediated periodontal treatment over traditional therapy is minimal at best. Lastly, there is limited evidence suggesting that lasers used in an adjunctive capacity to SRP may provide some additional benefit. Establishment of a sound evidence base for laser usage in treatment of chronic periodontitis will require randomized, blinded, controlled, longitudinal, clinical trials. Given the inherent expense, requirements of time, and number of clinicians required to conduct such studies, this may require multicenter collaborative studies.

ACKNOWLEDGMENT

The author thanks the staff of the University of Missouri School of Dentistry library for their considerable

effort in locating and copying the substantial number of articles reviewed for this article.

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Accepted for publication January 16, 2006.