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The biologic rationale for the use of lasers in dentistry

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Whenever laser energy is applied to oral tissue, it is incumbent on the dentist (or hygienist) to understand the biologic rationale for its use. Dentists can choose from a variety of wavelengths to use in the oral cavity. A complete understanding of the interaction between each of these different laser wavelengths and the target tissues is essential to ensure optimal treatment results. A separate article discussed the four different types of tissue interaction—absorption, reflection, scatter, and transmission. From that discussion, it is understood that optimal therapeutic effects result when the wavelength best absorbed by the target tissue is selected for use; however, the choice of the best laser for a certain procedure depends on much more than just matching emission spectra of lasers to absorption spectra of tissues. The type of delivery system best able to deliver the wavelength to the target, the composition of the tissue surrounding the target tissue, and the potential for necrosis of the surrounding tissue also must be taken into account. Other articles in this issue discuss in detail the use of lasers in the various disciplines of dentistry—prosthetics, periodontics, pedodontics, endodontics, implantology, cosmetic and operative dentistry, and oral and maxillofacial surgery. Those articles discuss how lasers are best used in each discipline; this article discusses why specific lasers should be used. Box 1 lists the uses of lasers in the various disciplines of dentistry. This list is by no means complete; as the field of laser dentistry expands, new uses are discovered on a regular basis.

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Box 1. Laser use in dentistry

Periodontics

Initial (nonsurgical) pocket therapy
Nonosseous gingival surgery
- Frenectomy
- Gingivectomy
- Graft

Periodontal regeneration surgery
- De-epithelialization
- Removal of granulomatous tissue
- Osseous recontouring

Fixed prosthetics/cosmetics

Crown lengthening/soft tissue management around abutments
Osseous crown lengthening
Troughing
Formation of ovate pontic sites
Altered passive eruption management
Modification of soft tissue around laminates
Bleaching

Implantology

Second-stage recovery
Peri-implantitis

Removable prosthetics

Epulis fissurata
Denture stomatitis
Residual ridge modification
- Tuberosity reduction
- Torus reduction
- Soft tissue modification

Pediatrics/orthodontics

Exposure of teeth
Soft tissue management of orthodontic patients

Oral surgery/oral medicine/oral pathology

Biopsy
Operculectomy
Apicoectomy
Oral soft tissue pathologies

Operative dentistry

Deciduous teeth
Permanent teeth

Delivery systems

The field of lasers in general practice essentially began with the introduction of the American Dental Laser (Birmingham, Michigan) dLase 300 neodymium:yttrium-aluminum-garnet (Nd:YAG) laser in 1990. Before the introduction of this instrument, most dental lasers used bulky articulated arms for their delivery systems. These articulated arms were not conducive to the practice of general dentistry, owing to the long learning curve needed to master their use and the difficulty of delivering the laser energy to the entire oral cavity. Articulated arm delivery systems consist of a series of rigid hollow tubes with mirrors at each joint (called a *knuckle*) that reflect the energy down the length of the tube. These joints exist to allow the delivery arm to be bent and configured in such a way as to bring the handpiece close

Fig. 1. Articulated arm delivery system. (Courtesy of DEKA Laser Technologies LLC, Ft. Lauderdale, FL.)

to the target tissue. The laser energy exits the tube through a handpiece (Fig. 1). Strauss [1] described the intraoral use of an articulated arm delivery system. He stated that it is a difficult way to remove discrete lesions within the oral cavity because of the awkward three-dimensional maneuverability of the arm. A second problem with the use of articulated arms is the alignment of the mirrors. To transmit the laser energy efficiently, the mirrors at each knuckle must be aligned precisely. A misalignment of the mirrors could cause a drop-off in the amount of energy transmitted to the handpiece. The mirrors could go out of alignment through the normal use of moving the articulated arm for each new procedure or if the laser is moved from treatment room to treatment room. Articulated arm delivery systems are noncontact systems (ie, the handpiece or its attachments do not come into contact with the target tissue). Dentists are familiar with contact technology: The fissure bur contacts the enamel during tooth preparation. The curet contacts the root surface during scaling and root planing. The scalpel contacts the soft tissue when incising. Using a technology in which there is no contact between the instrument and target tissue can be challenging at first. This is one major reason for a longer learning curve with these instruments compared with contact technology instruments.

The American Dental Laser dLase Nd:YAG system was the first such instrument to use a fiberoptic delivery system. This fiberoptic technology allows for contact with the target tissue. The fiberoptic cables are attached to a small handpiece similar in size to a dental turbine and are available in sizes ranging from 200 μm in diameter to 1000 μm in diameter. Fiberoptic cables also are relatively flexible. This flexibility allows for easy transmission of the laser energy throughout the oral cavity, including into periodontal pockets. Fiberoptic delivery and articulated arm systems are not the only two delivery systems currently on the market. One manufacturer has developed a hollow waveguide delivery system. In contrast to an articulated arm system, this waveguide is a single long, semiflexible tube, without knuckles or mirrors. The laser energy is transmitted along the reflective inner lumen of this tube and exits through a handpiece at the end of the tube (Fig. 2). This handpiece comes with various attachments that the dentist may select, depending on the procedure to be performed, and may be used either in contact or out of contact with the target tissue. Fig. 3 illustrates fiberoptic cables of various diameters and handpieces from a carbon dioxide (CO_2) waveguide delivery system.

The final delivery system is the air-cooled fiberoptic delivery system. This type of delivery system is unique to the erbium family of lasers. A conventional fiberoptic delivery system cannot transmit the wavelength of the erbium family of lasers, owing to the specific characteristics of the erbium wavelength. These special air-cooled fibers terminate in a handpiece with quartz or sapphire tips. These tips are used slightly (1–2 mm) out of contact with the target tissue.

Since the introduction of the dLase 300, general practitioners have seen the number of wavelengths and manufacturers available to them increase

Fig. 2. Waveguide delivery system. (Courtesy of Opus Dent, Santa Clara, CA.)

from one manufacturer of one wavelength to eight different manufacturers offering six different wavelengths. Table 1 lists the wavelengths and manufacturers currently marketed in the United States.

Incision, excision, ablation

Most soft tissue laser procedures can be categorized into one of three simple processes: incision, excision, or ablation. Whether the dentist is performing a soft tissue tuberosity reduction (excision) to enhance the results of a removable prosthetic treatment plan, performing a small biopsy of a large lesion on the palate (incision), or removing an area of lichen planus from the buccal mucosa (ablation), the basic processes are the same, no matter which wavelength is used. There is a difference in how the various lasers interact with oral tissue, depending on the ability of the target tissues to absorb the laser energy. The most significant differences among the different types of oral soft tissues are the pigmentation, vascularity, and water content. As an example of how these differences affect the selection of a wavelength, imagine two patients who need a gingivectomy. The first patient has light, coral pink gingiva; the second patient has dark, melanotic gingiva. The chromophore for the CO_2 laser is water. There would be no difference in the cutting efficiency when using a CO_2 laser on these patients.

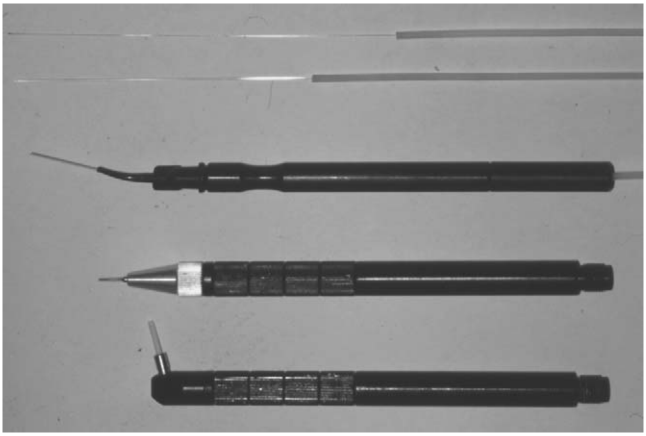

Fig. 3. Fiberoptic cables of various diameters and handpieces from a CO_2 waveguide delivery system. (Courtesy of Robert Convissar, DDS, New York, NY.)

The coral pink and the melanotic gingiva would respond equally well to the CO_2 laser. Using the same patient models, gingivectomies performed with the Nd:YAG and diode lasers would result in a significant difference in the cutting efficiency. Diode and Nd:YAG lasers are absorbed preferentially by tissue pigments, such as hemoglobin and melanin. The darker melanotic gingiva would absorb the laser energy much more easily; it would cut more quickly and easily than the coral pink gingiva. The melanotic tissue might cut more rapidly than the clinician would like, possibly damaging the tissue or creating a larger zone of thermal necrosis around the target tissue. In this case, laser parameters (pulse duration, hertz, joules) would need to be

Table 1
Wavelengths currently available for sale in the United States

Wavelength	Manufacturer	Delivery system
Diode, 810–830 nm	Biolase	Fiberoptic cable
	Hoya/Conbio	Fiberoptic cable
	Zap Lasers	Fiberoptic cable
	OpusDent	Fiberoptic cable
	Biolitec*	Fiberoptic cable
Nd:YAG, 1064 nm	Biolase	Fiberoptic cable
	Lares Research	Fiberoptic cable
	Millenium Dental Technologies	Fiberoptic cable
Er:Cr:YSGG, 2780 nm	Biolase	Air-cooled fiberoptic/handpiece
Er:YAG, 2940 nm	Hoya/Conbio	Air-cooled fiberoptic/handpiece
	OpusDent	Hollow waveguide
CO_2, 10,600 nm	OpusDent	Hollow wave guide
	Deka	Articulated arm

* The wavelength produced by the Biolitec laser is 980 nm; all other diode lasers produce a wavelength of 810–830 nm.

modified from one patient to another. Laser parameters suggested by the manufacturers are for the "average" patient. These parameters must be modified based on many factors, with tissue pigmentation being one crucial factor. This is an important fact that might be lost on new laser users.

Another case example can be used to illustrate the effect of tissue vascularity and water content on the effectiveness of lasers. Imagine two orthodontic patients wearing full bands and arch wires. The first orthodontic patient has immaculate home care. The gingiva is firm, pink, and stippled. The second patient's home care is practically nonexistent. The combination of poor home care and a foreign body (orthodontic appliance) acting as a plaque trap has led to gingival hyperplasia. The gingiva is hyperemic, red, and inflamed. Both patients need gingivectomies to increase the gingivoincisal length of the teeth. Comparing the results of treatment with a diode and an Nd:YAG laser would show large differences in treatment outcomes. The chromophore that is absorbing the laser energy in this case is the hemoglobin. The hyperemic, swollen tissue with more vascularity cuts more quickly with the diode and Nd:YAG lasers than the healthy pink tissue. In the case of the CO_2 laser gingivectomies, the chromophore is water. The swollen, hyperemic tissue would have more water content and would absorb the CO_2 laser energy more readily.

These examples illustrate that the laser user must consider the quality of the target tissue. With proper training, a laser user is able to evaluate and treat the above-described cases with any wavelength simply by adjusting the laser parameters to suit the tissue. Selection of the correct wavelength is not crucial to the success of these cases. Selection of the proper laser parameters *is* crucial; this is precisely why laser training is so important. The new laser purchaser must take into account the type of training offered by the manufacturer. Will the training be at a sales seminar? Will the training be in the purchaser's office? Will it include live patient demonstrations? Will it include a hands-on "wet lab"? Alternatively, is the training nothing more than a workbook with a CD-ROM? These are all critical issues that must be discussed before the purchase of a laser is completed. The issue of training is discussed in more detail in the article on practice management in this issue.

Gingival surgery

According to statistics compiled by the American Dental Association, dentists spend more time in the delivery of prosthetic care than any other field except operative dentistry. The 2000 Survey of Dental Practice [2] showed that the average general dentist spent 35.7% of his or her time in the delivery of operative dentistry and 19% of his or her time in the delivery of prosthetic care. A review of the procedures listed in Box 1 shows that most of the laser procedures in fixed, removable, and implant prosthetics are variations of the simple gingivectomy. The same may be said about most soft tissue procedures in pediatric dentistry and many minor oral surgical procedures performed by general practitioners. Wigdor et al [3] described the advantages of lasers over cold steel surgical procedures as follows:

1. Dry and bloodless surgery
2. Instant sterilization of the surgical site
3. Reduced bacteremia
4. Reduced mechanical trauma
5. Minimal postoperative swelling and scarring
6. Minimal postoperative pain

In his discussion of soft tissue surgery, Bader [4] listed the same advantages and specified that when performing frenectomies in younger patients, the laser is particularly benign compared with traditional surgery. Parkins [5] stated that children and adolescents are among the best candidates for laser use because they are particularly bothered by pain, bleeding, and extra postoperative office visits. He believed that elimination of hemorrhage and postoperative comfort are the two greatest benefits to pediatric patients. His experience showed that any soft tissue laser may be used for ankyloglossia, exposure of teeth to aid eruption, and treating the effects of dilantin hyperplasia in a special needs patient. Every soft tissue laser fulfills the advantages enumerated by Wigdor et al [3]. Every laser on the market has the ability to perform incisions and excisions of soft tissue, while destroying bacteria at the surgical site. Reduced mechanical trauma to the tissue, less postoperative pain, swelling, and scarring are not unique to any specific wavelength. For most laser dentistry procedures, the choice of which wavelength is a matter of personal preference; for other procedures, the use of the correct wavelength can make the difference between success and failure. Some laser users prefer the CO_2 wavelength because of its high absorption in water and its lack of thermal penetration; others prefer Nd:YAG because of its absorption by tissue pigments and its deeper depth of penetration. Still other clinicians prefer diode units because of their compact size and portability. Many dentists now are using the erbium family of lasers for soft tissue due to their high absorption in water and lack of thermal penetration. Arguments can be made for or against any of these wavelengths for specific procedures. The fact is that any well-trained dentist who understands the physics and emission characteristics of each of the lasers, along with the absorption spectra of the target and surrounding tissues, can be successful with most lasers. Rather than defending the use of specific lasers for each procedure listed in Box 1, this article discusses only the procedures in which use of a specific wavelength is crucial to the success of the procedure.

Nonsurgical periodontal therapy

It is a primary tenet of periodontics that periodontal disease is a bacterial infection. Nonsurgical periodontal therapy since the 1990s has focused on bactericidal treatment. The use of systemically and locally delivered antibiotics to fight periodontal disease is well documented. Doxycycline [6–8] and metronidazole [9–11] are used systemically to fight periodontal infections. Tetracycline-impregnated cords [12,13] and injection of minocycline sphericals [14–17] are relatively recent additions to the armamentarium of antibiotic therapies used in the treatment of periodontal disease. Many patients who have chronic periodontal disease are given small maintenance doses of tetracycline twice daily for 90 days or more in an effort to maintain a constant antibacterial effect in the fight against periodontal disease [18,19]. All of these therapies have the same goal: the removal of bacteria from the periodontium to improve the periodontal health of the patient. One essential criterion for selection of an appropriate wavelength for nonsurgical periodontal therapy is definitive proof of a bactericidal effect on periodontal tissues. Another essential criterion is the delivery system. The practitioner must be able to deliver a bactericidal wavelength to the tissue efficiently. If a bactericidal wavelength is available, but the delivery system does not lend itself easily to applications within the periodontal pocket, that wavelength is therapeutically useless. A third criterion is the effect of the wavelength on the surrounding tissue. In the case of nonsurgical periodontal therapy, the surrounding tissue is the hard tissue of the root surface. A bactericidal wavelength easily delivered into the periodontal pocket must not cause any harmful effects to the root surface. The ideal properties of a wavelength that can be used successfully for nonsurgical periodontal therapy are bactericidal, easy to deliver into the pocket, and safe enough to use in a periodontal pocket so that it causes no harm to the root surface.

The previous section discussed the various delivery systems currently on the market. The articulated arm delivery system does not meet the criterion of easily delivering laser energy to the periodontal pocket. This is a noncontact delivery system. The distance from the handpiece to the target tissue can range from 1.5 cm to more than 6 cm. A focal distance of this length would not allow for the laser energy to enter the periodontal pocket. Waveguide delivery systems terminate in handpieces similar in size to a dental turbine. These handpieces can accept various attachments, depending on the intended use of the laser. None of the attachments are small or flexible enough to enter the periodontal pocket and effectively deliver laser energy to the pocket lining. The only two soft tissue wavelengths that currently meet the criterion of having a delivery system able to deliver laser energy efficiently and effectively to the periodontal pockets for nonsurgical periodontal therapy are Nd:YAG and diode.

The next criterion in evaluation of a wavelength for nonsurgical periodontal therapy is the wavelength's bactericidal ability. Both of these wavelengths have been shown to be extremely effective against periodontal pathogens in vivo and in vitro [20–24]. In a study by Moritz et al [21] using diode lasers in vivo, bleeding index improved in 96.9% of the population compared with a 66.7% improvement in the population that did not undergo laser treatment. These investigators concluded that the diode laser revealed a bactericidal effect, helped reduce inflammation, and supported healing of the periodontal pockets through the elimination of bacteria. Neill and Mellonig [23], in a double-blind, split-mouth study, assigned patients to one of three treatment regimens: scaling and root planing alone, Nd:YAG laser treatment with root planning, and control group with no laser treatment or scaling. Their results showed that the laser-treated patients exhibited significantly greater improvement in measurement of their gingival index and gingival bleeding index. At 6 months postoperative, the laser-treated group showed significant improvement in attachment gain.

Bader [4] described the advantage of laser curettage as enhanced bacterial reduction with good hemostasis in a procedure that is less invasive than open flap surgery. This procedure is technique sensitive and merits a brief discussion. In this procedure, the laser energy is directed solely onto the soft tissue lining of the periodontal pocket. The optical fibers used to deliver the laser energy are only end-cutting fibers (ie, the energy comes out only from the fiber tip, not along the length of the fiber). When the laser energy is directed parallel to the root surface, the laser removes from the soft tissue the bacteria and their exotoxins (eg, hyaluronidase, collagenase) that are responsible for breakdown of the periodontium. When the laser energy is directed onto the root surface rather than the soft tissue lining of the periodontal pocket, the root surface can be damaged.

Schwartz et al [25] studied the effects of diode laser energy on root surfaces. They concluded that when the laser energy is directed onto the root surface, severe damage, including crater-like defects and grooves, occurred on the root surface. Morlock et al [26] found similar results with Nd:YAG lasers. These studies and others [27–31] led the American Academy of Periodontology [32] to conclude that neither the diode laser nor the Nd:YAG laser is an alternative to root planing. The key word in the American Academy of Periodontology report is *alternative*. With diode and Nd:YAG intrasulcular treatment protocols, as with most dental laser treatment protocols, the laser is used as an *adjunct* to standard treatments rather than as a replacement for standard treatments. Laser curettage of periodontal pockets is unsuccessful unless it is combined with standard scaling and root planing to remove bacteria and accretions from the root surface. Neill and Mellonig [23] and Moritz et al [21] emphasized in their in vivo clinical studies that the most significant improvement was found in the group of patients who had conventional scaling combined with laser treatment. Conventional instruments are used for standard scaling and root planing procedures, and laser energy is used solely on the soft tissue lining the pocket.

Bader's [4] description of his technique emphasizes the point that the laser tip is moved circumferentially around the tooth rather than onto the root surface and is followed by hand instrumentation. Neill and Mellonig [23] emphasized that the tip of the fiberoptic makes light contact against the pocket epithelium rather than the root surface and is kept in a sweeping motion from the base of the pocket moving coronally. The conclusion to be reached from this research is that diode and Nd:YAG lasers are safe and effective wavelengths to be used in nonsurgical periodontal therapy when used according to established protocols. As long as the laser energy is not directed onto the root surface, wavelengths have been shown to be effective instruments in nonsurgical periodontal therapy. This technique is discussed in detail in the article on laser use for initial periodontal therapy. Fig. 4 illustrates a diode laser fiber being introduced into a periodontal pocket. The fiber (slightly elongated for illustrative purposes) is parallel to the long axis of the tooth, and the fiber tip does not come into contact with the root surface.

Regenerative periodontal surgery

The design and raising of a full-thickness mucoperiosteal flap for any surgical procedure, whether for periodontal or oral surgery, is a relatively straightforward procedure. Essentially the base must be wider than the crest to ensure adequate blood flow to the flap. Most general practitioners have the ability to raise and suture back into place a full-thickness mucoperiosteal flap. For the purposes of this discussion, it is assumed that the flap is raised by a conventional method (scalpel). The most difficult step in a typical periodontal surgical procedure, and the step that ultimately determines the success or failure of the surgical procedure, is the removal of the diseased tissue from the surgical site. If the diseased soft tissue and calcified accretions on the root surface are not removed, the surgical procedure is doomed to failure. Many techniques and instruments have been available for removal of this diseased tissue. Historically the instruments of choice have been curets and other surgical steel instruments. Lasers now are being used for this procedure. Whatever wavelength is used for regenerative periodontal surgery must not cause any harmful effects on the root surfaces. As addressed in the previous discussion of the use of lasers for nonsurgical periodontal therapy, some wavelengths can cause harm to the root surface.

Fig. 4. Diode laser fiberoptic entering a periodontal pocket parallel to the long axis of the tooth. (*From* Convissar RA. Lasers in general dentistry. Oral Maxillofac Surg Clin N Am 2004;16:165–79; with permission.)

Trylovich et al [27] evaluated the effects of the Nd:YAG laser on fibroblast attachment to endotoxin-treated root surfaces. These investigators concluded that the laser alters the cementum surface in such a way that it makes it unfavorable for fibroblast attachment. Spencer et al [28], Thomas et al [29], and others [30,31] also found that when the Nd:YAG laser is used directly on the root surface, the surface is altered unfavorably. Schwartz et al [33] compared a diode laser, an erbium:YAG (Er:YAG) laser, and scaling and root planing. The in vivo study selected teeth scheduled for extraction. The teeth were assigned into one of three groups: scaling, Er:YAG treatment, or diode treatment. The diode group had the highest mean number of craters on the root surface (14.6 craters), the scaling and root planing group had a mean of 3 craters per sample, and the Er:YAG group had no craters. The diode-produced craters also were significantly deeper than the craters produced by hand instrumentation. Schwartz et al [33] concluded that the diode laser was unsuitable for calculus removal because it altered the root surface in an undesirable way. This study reached the same conclusions as Kreisler et al [34], in his evaluation of the effects of diode laser irradiation on root surfaces. These results lead to the conclusion that diode and Nd:YAG lasers may be used for initial periodontal therapy and soft tissue excision/ablation procedures, but extreme caution must be taken to ensure that neither of these wavelengths has a significant interaction with the root surface during regenerative periodontal surgery.

The results of Schwartz's in vivo study [33] warrant further attention. The results showed that Er:YAG treatment left no craters on the root surface. The conclusion regarding the use of Er:YAG laser on root surface was that Er:YAG provided selective subgingival calculus removal on a level equivalent to that provided by scaling and root planing. In vivo, Er:YAG laser instrumentation produced nearly smooth root surfaces, with no cracks or thermal effects. The results of this study are similar to two previous studies using the Er:YAG wavelength on root surfaces. Both studies [35,36] showed that Er:YAG lasers are excellent tools that can be used on root surfaces safely and effectively. One of the most significant studies detailing the potential for the use of Er:YAG for periodontal regeneration was performed by Schwartz et al [37]. They studied the in vivo effects of the Er:YAG laser on the biocompatibility of periodontally diseased root surfaces and periodontal ligament fibroblasts. Their results showed that the Er:YAG laser promotes the attachment of periodontal ligament fibroblasts on previously diseased root surfaces and that the surface structure of Er:YAG laser instrumented roots offers better conditions for the adherence of periodontal fibroblasts than scaling and root planing. These studies, when taken together, show that the Er:YAG laser can promote periodontal regeneration by removing calculus from the root surface, leaving the root surface smooth and better able to create an environment for successful attachment of new connective tissue fibers. A distinction must be made here with respect to the erbium class of dental lasers. There is a great deal of difference between the effectiveness of the Er:YAG laser (2790 nm) and the erbium-chromium-yttrium-scandium-gallium-garnet (Er:Cr:YSGG) laser (2940 nm) in regenerative surgical periodontics. There are currently no peer-reviewed articles in the literature that can defend the use of the Er:Cr:YSGG laser for periodontal treatment of any kind. Dentists using Er:Cr:YSGG lasers have yet to report in the scientific literature any use of this wavelength for osseous periodontal surgery. The American Academy of Periodontology has stated that even though the Er:Cr:YSGG wavelength has received US Food and Drug Administration (FDA) safety clearance, there are neither reports in the literature nor animal or human studies that may be used to defend its use [32]. In comparison, the American Academy of Periodontology concluded that "the Er:YAG laser demonstrated the best application of laser use directly on hard tissue, leaving the least thermal damage and creating a surface that suggests biocompatibility for soft tissue attachment. Studies have shown the ability of the Er:YAG laser to remove lipopolysaccharides from root surfaces, facilitate removal of the smear layer after root planing, remove calculus and cementum" [32]. The Er:YAG laser is an excellent choice to use in regenerative periodontal surgery to prepare the root surface for new attachment of connective tissue. The problem is ensuring that the connective tissue, rather than the epithelium, has an opportunity to grow and create new attachment. Clinicians must ensure that the fibroblasts have the opportunity to adhere to the root surface by preventing the epithelium from growing faster than the connective tissue and creating a long junctional epithelium.

The principle of epithelial exclusion has been in the periodontal literature for more than 50 years [38]. Epithelium grows more quickly than connective tissue. After a flap is raised, and the diseased tissue is removed from the surgical site, an epithelial exclusion technique must be used to prevent the epithelium from growing. When the epithelium is prevented from growing, the connective tissue grows in its place. This connective tissue then establishes new attachment to the root surface, provided that the root surface has not been damaged from the surgical procedure, and the surface is denuded of all bacteria and infected material. If the epithelium is not prevented from growing as the surgical procedure heals, the result is a long junctional epithelium, rather than a true connective tissue attachment. As discussed earlier, the use of barrier membrane and epithelial exclusion techniques is not new to regenerative periodontal therapy. The question to be raised is whether there is any place in periodontics for the use of lasers to retard epithelial downgrowth.

The answer to this question may be found in a series of publications. The first article, by Rossmann et al [39], used monkeys to determine the ability of the CO_2 laser to prevent epithelial migration after flap surgery. In this split-mouth study, periodontal defects were produced bilaterally. Both sides were treated with open flap débridement. On one side, the epithelium was removed with a CO_2 laser. The other side served as the control. The results showed that epithelialization of the CO_2 irradiated side was delayed by at least 7 days, allowing for new connective tissue to grow. Just as important, the results showed that the healing of the connective tissue was not retarded at all. The investigators concluded that the CO_2 laser can be used to delay the apical downgrowth of epithelium and that this technique was less technically demanding and more time efficient than other currently known methods of epithelial retardation. Israel et al [40] used the CO_2 laser in a human study. They performed open débridement and placed a notch on the teeth at the crest of the alveolar bone before closure. At reentry 90 days later, every nonlased tooth developed a long junctional epithelium the length of the root to the base of the notch. On the lased side, the notch was filled with connective tissue and some repair cementum. Rossmann et al [41] refined this technique with a study on beagles that found similar results. This technique subsequently was performed clinically [42]. The in vivo human results showed that this CO_2 laser de-epithelialization technique has the ability to obtain new clinical attachment with bone fill in previously diseased sites. The investigators concluded that this technique has shown significantly better results than the results obtained through conventional osseous grafting alone.

The results of the CO_2 de-epithelialization studies combined with the Er:YAG studies of the effects on root surfaces lead to the conclusion that the most effective method of regenerative periodontal surgical techniques would be a double-wavelength technique. This technique would use the Er:YAG to débride the open surgical site, clean and sterilize the root surface, and prepare the root surface for the adhesion of fibroblasts. The CO_2 laser would remove the epithelium, which would allow the fibroblasts to adhere and proliferate, creating new attachment. This double-wavelength technique shows tremendous promise in the field of regenerative periodontal surgery. More university-based or hospital-based, split-mouth studies involving a larger number of patients are necessary before this technique can be considered fully documented; however, there seem to be more than enough studies to confirm that there is a biologic rationale for the use of this technique.

This technique is not the only technique that is advocated by laser practitioners to regenerate lost periodontal structures. As noted earlier, diode and Nd:YAG lasers have the ability to improve the gingival index, decrease pocket depth, decrease bleeding on probing, decrease the bacterial content of periodontal pockets, and improve the overall health of the periodontium. The author has had a great deal of success treating molars with furcation involvements and class II mobility nonsurgically with Nd:YAG and diode lasers. To date, the only published studies suggesting that these wavelengths can create regeneration of the periodontal apparatus are anecdotal [43–46] and do not stand up to the scrutiny of the scientific method. Research of the type needed to verify these claims is expensive and time-consuming. Neither the laser companies nor dental schools have yet allocated precious resources to study these wavelengths in sufficient detail to verify these claims. As more research is performed, the field of laser dentistry will expand with more peer-reviewed literature showing that many different wavelengths using different techniques will be able to create regeneration of periodontal tissues.

Osseous resection

Many full-thickness mucoperiosteal flap procedures include osseous resection. The only wavelengths cleared by the FDA for osseous surgery are the erbium family of lasers. Er:YAG and Er:Cr:YSGG are the only wavelengths that have the ability to ablate osseous tissue safely. There is a great difference between FDA clearance for specific procedures, however, and proof of efficacy when using lasers for those procedures. As addressed earlier, the American Academy of Periodontology report [32] discusses the fact that even though Er:Cr:YSGG has FDA clearance, peer-reviewed literature defending its use for osseous procedures is lacking. In comparison, the report does enumerate four articles in its discussion of the Er:YAG wavelength, all of which led the American Academy of Periodontology to state that the Er:YAG wavelength shows ‘‘the best application of laser use directly upon hard tissue.’’ Four articles is hardly enough evidence to accept unequivocally the role of this wavelength in osseous surgery. This is one area of laser dentistry that needs more research. The role of lasers in osseous surgery is discussed in more detail in the article on erbium lasers in this issue.

Endodontics

It is a well-accepted tenet of endodontic therapy that the cause of periapical lesions and loss of tooth vitality is bacterial contamination. Without the presence of bacteria, teeth do not lose vitality, and periapical lesions do not develop. Spangberg [47] stated that the importance of infection now is accepted as the major factor for the development of periradicular inflammatory disease. Schilder [48] stated that the success of endodontic treatment depends on the dentist’s ability to clean and disinfect the complex canal system three dimensionally, then to fill and seal this space completely. In a landmark study, Kakehashi et al [49] took normal rats and germ-free rats and exposed their pulps. By day 8, all normal rats had nonvital, necrotic pulps and periapical abscesses. The germ-free rats never lost pulp vitality. No granulomas or abscesses formed. Dentinal bridges began to form by day 14, with complete healing of the exposures by day 28, even with gross food impaction in the endodontic access holes. Other studies have compared the success rates of endodontically treated teeth with positive cultures with endodontically treated teeth with negative cultures. Cultures were taken immediately before obturation of the canals. The success rate of teeth with negative cultures immediately before obturation was significantly higher than the success rate of teeth with positive cultures [50,51].

Sundqvist et al [52] stated that most cases of endodontic failure are thought to involve a continuing infection of the root canal system. Other researchers, notably Nair et al [53] and Sjogren et al [54,55], concluded that the most probable reason for failure of endodontic treatment is the presence of a persisting infection. In 1957, it was known that intact teeth that became devitalized as a result of trauma, rather than decay, harbored pathogenic bacteria as a result of the trauma [56]. This early study by MacDonald et al [56] has been substantiated by Wittgow and Sabiston [57]. These studies illustrate the need for bacteria to be present to cause endodontic infections and bony rarefactions at the apex of teeth. It also may be concluded from these studies that when the root canal system is sealed properly after the removal of bacteria, the endodontic treatment is successful. The criterion for selection of an ideal wavelength for endodontic therapy is the ability to deliver bactericidal energy to the root canal system. Every laser currently on the market has been proved to be bactericidal. More specifically, lasers have been shown to be bactericidal in root canals in vivo and in vitro. Moritz et al [58] and Gutknecht et al [59] evaluated the diode and Nd:YAG lasers in root canals. Both wavelengths were shown to be highly suitable for killing bacteria in infected root canals. Schoop et al [60] subjected 220 extracted human teeth to bacteriologic evaluation. Their results showed that there was a decisive bactericidal effect when an Er:YAG laser was introduced into an infected root canal. These investigators concluded that the Er:YAG laser can be used to eliminate bacteria from root canals [60]. Mehl et al [61] inoculated 90 extracted anterior teeth with *Escherichia coli* or *Staphylococcus aureus*. Their results after using Er:YAG laser in an attempt to sterilize the canals showed that the Er:YAG laser exerts efficacious antimicrobial effects in dental root canals.

Most laser delivery systems currently on the market have the ability to deliver laser energy to the root canal system. Conventional fiberoptic cables (Nd:YAG, diode) can be placed directly into root canals. Waveguide and air-cooled fiberoptic delivery systems (Er:YAG, Er:Cr:YSGG, CO_2) have handpiece attachments that can deliver laser energy into the root canals. Fig. 5 shows a variety of endodontic attachments available for the Er:Cr:YSGG laser handpiece. Fig. 6 shows one of the Er:Cr:YSGG attachments in a root canal.

If the sole purpose of using a laser for endodontic treatment is to sterilize a root canal system, any wavelength would work. With the exception of the articulated arm delivery system, every delivery system would work. If the goal of using a laser in endodontic therapy is more than just sterilization of the canal, the other steps in endodontic treatment must be addressed. The goals of endodontic therapy may be summarized as follows:

1. Débridement of the canal
2. Instrumentation of the canal
3. Removal of the smear layer
4. Sterilization of the canal
5. Sealing of the main and all accessory canals

Fig. 5. Variety of endodontic attachments for the Er:Cr:YSGG laser handpiece. (Courtesy of Biolase, San Clemente, CA.)

When endodontic access and initial débridement of the canal is completed, the next critical steps are removal of the smear layer and sterilization of the root canal system. When the bacteria are removed from the root canal system, and the system is sealed off with gutta percha, the periapical pathology heals. Removal of the smear layer is an important step in the process of canal sterilization. It is important to remove the smear layer from the root canal system because the smear layer occludes the dentinal tubules. Fogel and Pashley [62] stated that the smear layer may harbor bacteria and bacterial products. Bacteria may be multiplying within the dentinal tubules.

Fig. 6. Er:Cr:YSGG endodontic attachment in a root canal. (Courtesy of Biolase, San Clemente, CA.)

If bacteria are not removed from the tubules, this could lead to failure of the endodontic treatment. Smear layer removal allows for superior cleaning and sterilization of the root canal. Takeda et al [63] compared 17% ethylenediaminetetraacetic acid (EDTA), a chelating solution commonly used in endodontics to enlarge canals and remove the smear layer, with 6% phosphoric acid and Er:YAG laser energy. Sixty extracted human teeth were used in their study. The results showed that the Er:YAG laser was the most effective in removal of the smear layer from root canal walls [63]. In a separate study, Takeda et al [64] used 36 extracted teeth in a study to evaluate further the use of Er:YAG lasers inside root canals. Their results showed the Er:YAG laser–treated walls were free of debris, with open dentinal tubules. Takeda et al [64] concluded that the Er:YAG laser irradiation efficiently cleaned the root canal walls. A further study concluded that Er:YAG lasers are effective in removing debris and the smear layer from root canal walls [65]. When Er:YAG lasers were compared with other lasers, notably argon and Nd:YAG lasers, the results showed that the Er:YAG laser was the most effective wavelength and more effective than 17% EDTA in removal of smear layer from root canal walls [66]. The sole remaining step in endodontic therapy is the obturation of the canal. Er:YAG lasers have shown a remarkable ability to enhance the results of the obturation process. Application of Er:YAG energy to the root canal walls has been shown to increase the adhesion of epoxy-based root canal sealers (AH26, AH Plus, Topseal, Sealer 26, and Sealer Plus) to the canal walls. Pecora et al [67] used 99 extracted maxillary molars with an Instron Universal testing machine. Their results showed that there was a statistically significant difference between laser-treated dentin and EDTA-treated dentin with respect to adhesion of sealer to the dentin walls [67]. Sousa-Neto et al [68] used 40 extracted human molars with an Instron Universal testing machine. Their results showed that laser application significantly increased the adhesion of root canal sealers. Research also has attempted to respond to the concerns of laser energy flowing outside the root canal. One major concern would be the effect of laser energy on the periodontal ligament surrounding the tooth, just beyond the apex of the tooth. Research to date has concluded that the effects on the periodontal ligament when using Er:YAG laser energy is minimal, and no discernible effects on the periodontal ligament have been noted. Kimura et al [69] irradiated 20 extracted human teeth with Er:YAG laser energy. With the use of thermocouples and scanning electron microscopy, they discovered that the root surface temperature did not increase significantly, and there was no evidence of carbonization or melting.

All of this research involves the use of the Er:YAG laser wavelength of 2940 nm. The manufacturer of the Er:Cr:YSGG wavelength of 2780 nm has suggested the use of their unit for complete endodontic therapy, including instrumentation of the canal. This manufacturer has developed a series of thin, flexible endodontic tips that may be used to enlarge the root canal. This wavelength has been cleared by the FDA for endodontic instrumentation and débridement. There are many anecdotal reports of its use in endodontic therapy; however, there are not yet any peer-reviewed articles in the dental literature to substantiate the manufacturer's claims. The author is confident that in the near future, there will be peer-reviewed literature to validate the use of this wavelength for endodontic therapy.

All wavelengths have been shown to be bactericidal. Conventional and air-cooled fiberoptic delivery systems and waveguide delivery systems are capable of delivering bactericidal energy to the root canals. If instrumentation, removal of the smear layer, and sealing of the canals are the goal of laser use in endodontic therapy, the erbium family is the only group of wavelengths that can perform those tasks. Currently, Er:YAG lasers can be recommended based on a review of the literature. Er:Cr:YSGG has been approved and has many anecdotal reports, but as of this writing does not yet have peer-reviewed research to validate its use.

Operative dentistry

Practically since the profession of dentistry began, dentists have been seeking a method of removing decay painlessly and atraumatically without affecting the surrounding healthy dental tissue. The field of laser operative dentistry began with the FDA clearance of the Premier Laser Systems Er:YAG laser for caries removal and cavity preparation in 1997. Since then, three more erbium laser manufacturers have entered the market touting their ability to remove diseased hard tissue without the need for anesthesia. These lasers are indicated for all classifications of caries in enamel, dentin, and cementum for deciduous and permanent teeth. Erbium lasers are capable of removing not only decayed tooth structure, but also many nonmetallic restorations. Defective composite, glass ionomer, and compomer restorations may be removed quickly and easily without the use of analgesia. The one limitation of use with erbium lasers is the removal of metallic and porcelain restorations. Currently there is no laser that is able to remove defective amalgam, gold, or porcelain restorations. These restorations must be removed in a conventional manner before the laser may be used on the tooth to remove the recurrent decay. It is beyond the scope of this article to discuss in detail the process by which erbium lasers remove decay; this is discussed in the article on erbium lasers elsewhere in this issue.

The erbium family of lasers are the only wavelengths that are indicated for use in enamel, dentin, and cementum. For the sake of completeness, the Nd:YAG laser was cleared for removal of first-degree caries in enamel in 1995; however, as a result of the limitations of its approval, its use in operative dentistry is practically nonexistent today. The Nd:YAG laser has been supplanted by the much more versatile erbium family. This family of lasers consists of the Er:YAG laser with a wavelength of 2940 nm and the Er:Cr:YSGG laser with a wavelength of 2780 nm. Although many dentists are familiar with the name “Waterlase,” used to describe the Er:Cr:YSGG wavelength, this is actually a misnomer. The statement that water plays a role in the cutting ability of this laser compared with Er:YAG lasers, used in advertising for this company’s products for years, is scientifically invalid. Although the concept of “accelerated water” was proposed in 1994 by Riziou and DeShazer [70], scientific studies have shown this not to be the fact. Research by Fried et al [71] into the mechanism of Er:YAG and Er:Cr:YSGG concluded unequivocally that the mechanism proposed by Riziou and DeShazer [70] was incorrect. Hibst [72], using high-speed photography, also concluded that there was no scientific basis for any evidence of a “hydro-kinetic effect.” Freiberg and Cozean [73] concluded from their study of the erbium family of lasers that if a hydrokinetic effect exists, it is not effective on hard materials and does not contribute to enamel ablation.

Another significant difference is the absorption rate of these two wavelengths in water and hydroxyapatite. Coluzzi [74] stated that the Er:YAG wavelength has a 20% higher absorption in hydroxyapatite than Er:Cr:YSGG. Hibst [72] stated that the absorption of Er:Cr:YSGG in water is only half that of Er:YAG. Hibst [72] also compared Er:YAG and Er:Cr:YSGG with the same operating parameters, the same optical fiber, and the same spot size. He concluded that mass removal of dentin is greater and pulpal temperature increase is smaller during laser drilling with Er:YAG. Hibst [72] and Gimbel [75] also described multiple clinical trials detailing the need for anesthetic during operative procedures with the Er:YAG laser is only 2% to 10%. The author could find no similar peer-reviewed studies using the Er:Cr:YSGG wavelength. Does this mean that Er:YAG is superior biologically to Er:Cr:YSGG? It seems that there is a stronger biologic rationale for the use of Er:YAG over Er:Cr:YSGG in operative dentistry. The fact that Er:YAG causes less of a pulpal temperature increase and removes more dentin per pulse than Er:Cr:YSGG would lead one to that assumption; however, “wet-fingered” dentists put a great deal of stock in clinical results they can see. The clinical results dentists achieve with the Er:Cr:YSGG laser are within the bounds of clinically acceptable results. Research is ongoing with other wavelengths for hard tissue ablation. A new CO_2 wavelength of 9.6 μ is in development. The frequency-doubled alexandrite laser also is under development. The processes of development and testing of the alexandrite laser for dental use is discussed in the article on laser research in this issue. For the present, the Er:Cr:YSGG and Er:YAG lasers are clinically acceptable for use on dental hard tissue.

Summary

When selecting a laser for a specific procedure, the dentist must consider the interaction between the wavelength, target tissue, and surrounding tissue. For many dental procedures, most soft tissue lasers produce excellent results.

For these procedures, in which the selection of wavelength is a matter of personal preference, the selection of the correct operating parameters (joules, hertz, pulse duration) is crucial to the success of the procedure. For certain specific procedures, the choice of wavelength is crucial for the success of the procedure. A biologic rationale for the use of specific wavelengths for certain procedures has been outlined.

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