Textbooks in Contemporary Dentistry

Donald J. Coluzzi
Steven P.A. Parker
Editors

Lasers in Dentistry—Current Concepts

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Preface

The first laser specifically designed for dentistry was introduced in 1989 and used a crystal of neodymium-doped yttrium aluminum garnet (Nd:YAG) as its core active medium. Low average power photonic energy produced by this laser was delivered through a small-diameter optic fiber to target oral tissue. Such technology had been developed for use in medicine from 1975, and carbon dioxide (CO_2) lasers were commonly employed during the 1980s for general and oral surgery. Nowadays, approximately 15% of dentists worldwide own lasers, and there are about 30 indications for their use in dental treatment. Whether used in addition to or instead of conventional instrumentation, lasers provide many unique patient benefits.

This textbook is intended to provide information about the basic science and tissue interactions of dental lasers and display the most current examples of clinical use in every dental discipline. The clinical cases were chosen to show the results of proper laser use for a particular procedure, and the accompanying text explains the rationale, advantages, and precautions of that use, documented with numerous citations.

Research studies continue to provide collaborative evidence demonstrating the efficacy of the today's instrumentations. Furthermore, other investigations will enumerate novel clinical applications, and hopefully new laser wavelengths will be explored, developed to deliver highly specific power configurations to optimize laser-tissue interaction.

This book is the product of many highly respected dental clinicians, along with those in academia and involved in research throughout the world, and we are grateful for their efforts and their friendship. Most importantly, we acknowledge the love, understanding, and support of our spouses, Catherine Coluzzi and Penny Parker.

We hope you enjoy the book.

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Editors and Contributors

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a 1970 graduate of the University of Southern California School of Dentistry, is a clinical professor in the Department of Preventive and Restorative Dental Sciences at the University of California San Francisco School of Dentistry. He ran his own private practice of general dentistry in Redwood City, CA, and retired from it after 35 years. He is a life member of both the California Dental Association and the American Dental Association. He has served as a past president of the Academy of Laser Dentistry, received its Leon Goldman Award for Clinical Excellence, and is a past editor in chief of the *Journal of Laser Dentistry*. He has used dental lasers since early 1991 and holds advanced proficiency in Nd:YAG and Er:YAG wavelengths. He is a fellow of the American College of Dentists, is a University of California-certified dental laser educator, and is a member of Omicron Kappa Upsilon, the national dental honor society. He serves as a reviewer for several journals and is a founding associate of Laser Education International. He recently received the Outstanding Faculty Member Award from the American College of Dentists. Dr. Coluzzi has presented about lasers worldwide, coauthored two textbooks, and published several peer-reviewed articles and book chapters.

Steven P.A. Parker, BDS, LDS RCS, MFGDP

Dr. Steven Parker studied dentistry at University College Hospital Medical School, University of London, UK, and graduated in 1974. Dr. Parker has been involved in the use of lasers in clinical dentistry since 1990. He is closely involved in the provision of education in laser use in dentistry. He served as president of the Academy of Laser Dentistry in 2005–2006. In addition, Dr. Parker holds advanced proficiency status in multiple laser wavelengths. He was awarded mastership of the Academy of Laser Dentistry in 2008. Awards gained with the Academy of Laser Dentistry have been the Leon Goldman Award for Excellence in Clinical Laser Dentistry (1998) and the Distinguished Service Award (2010). From 2010, he has served an appointment as *professore a contratto* in the Department of Surgical Sciences and Integrated Diagnostics, University of Genoa, Italy. He also acts as international coordinator and lead faculty of the master of science (*Master Livello II*) degree program in laser dentistry at the University of Genoa. Dr. Parker has contributed chapters on aspects of laser use in dentistry in several textbooks and multimedia platforms. Additionally, he has received publication of over 40 peer-reviewed papers on the use of lasers in dentistry, including a series «The Use of Lasers in Dentistry» published in the *British Dental Journal* in 2007 and later as a textbook. He was the dental consultant to the UK Medical Health Regulatory Agency (Dept. of Health) in the 2008 (Revised 2015) publication «Guidance on the Safe Use of Lasers, Intense Light Source Systems and LEDs in Medical, Surgical, Dental and Aesthetic Practices.» He serves as associate editor of the *Journal of Lasers in Medical Science.* In addition, he serves as referee for many peer-reviewed dental journals worldwide. He maintains a private practice in Harrogate, UK.

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Concepts of Laser Use

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Lasers in Dentistry: Where to Begin?

Shally Mahajan, Vipul Srivastava, and Donald J. Coluzzi

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Core Message
Lasers have emerged as high-technology instruments and very helpful tools in all aspects of our daily lives. They have been slowly incorporated by dentistry over the last three decades. Our patients have come to expect treatment that is high quality, minimally invasive, comfortable, and patient friendly. Fortunately, a practice that utilizes lasers can fulfill those goals. The purpose of this chapter is to discuss some of the benefits of adopting lasers into a dental practice, what the clinician must know before purchasing a laser, and concepts of revenue generation. Moreover, a practitioner who is apprehensive about adopting the technology should also find helpful information to help in making a decision.

1.1 Introduction

Light has always fascinated mankind for many centuries. There have been innumerable references to light being a source of healing and curing many diseases for ancient cultures. Many Roman homes featured solariums [1], while they and the neighboring Greeks took daily sunbaths. The use of light for photodynamic therapy enabled early civilizations to treat a variety of dermatologic conditions using photosynthesizer chemicals found in plants. Over 200 years ago, physicians in Europe offered similar therapy using both artificial and natural light [2, 3].

At present, laser *technology* has become associated within indispensable and diverse applications such as metrology, science and engineering, medicine, communications, art and entertainment, research work, defense, and astronomy. It is impossible to even imagine state-of-the-art physics, chemistry, biology, and medicine research without the use of radiation from various laser systems.

In 1989 the first laser model specifically designed for the dental profession became available for treating oral soft tissue. Since then, many different wavelengths have been introduced, and the practitioner can easily use them on both hard and soft tissues for both surgery and healing. This new technology greatly expands the scope of procedures while making them easier and more comfortable for patients. Encouraged by an ever-increasing evidence of the safe and effective use of lasers, there are a growing number of practitioners embracing the technology and appreciating how their patients can benefit.

The question in this chapter's title may be properly expanded into «why buy a laser and what do I need to know when I buy it?» The following sections should provide many details for that answer.

1.2 A Buyer's Guide for Choosing a Laser

While investigating a product for our personal use or a piece of equipment for our practice, several aspects should be considered. We check for the features, benefits, assets, and liabilities to help us make sure that we are paying the right value of the product. A well-thought-out decision leads to a better business operation and good management. Hasty decisions can lead to financial distress and instability in career and unnecessary emotional stress. Similarly, before investing in a laser, we can ask the following questions:

? *Is a laser worth the investment; in other words, is there value for the money?*

✓ The first and foremost thing before buying a laser is to identify your practice goals because that will help you optimally understand the demands of your patient and how you would meet their expectations. Thus one response to the posed question is a multipart one: (1) Which procedures would I be able to perform with the laser that would produce beneficial results? (2) Can I achieve a good return on my investment by an additional fee for the procedures that I already perform conventionally? (3) Are there new procedures I can perform? Another section of this chapter will discuss these points in detail. After that analysis, the answer about value should be very straightforward. In any case, and depending upon the various treatment applications, lasers are available in a variety of wavelengths, sizes, and competitive prices.

Where would I put the laser? What should be the room size for the laser unit to fit?

The answers to these questions depend on which wavelength will be used for the procedure you have planned. For example, lasers for hard tissue—tooth preparation and osseous surgery—have a relatively large footprint, approximately the size of a standard dental cart. These lasers have air, water, and main utility requirements similar to that cart so the room should accommodate those. Other lasers such as soft tissue diodes are smaller units and only need small plug in adapters from AC power mains or are battery driven. They can be placed on any available small flat surface. In fact, some of those units are compact to the point of being shaped like a thick pencil and are self-contained. Technological sophistication continues to be developed, but each unit will have its unique space requirements.

What is the laser's portability and ease of setup?

As a corollary to the previous paragraph, all lasers have a degree of portability. The large units all have wheels and the smaller units can be lifted with one hand. Some have a wireless foot control pedal and the others have multiple cables to connect. Nonetheless, any unit can be moved between operatory rooms. Setting up the laser follows prescribed steps. Along with various safety features, the start-up protocol takes very little time. The delivery systems have specific accessories that are simple to attach and the displays on main screen are easily readable. If there are buttons for presetting parameters, they can be customized for a particular procedure. Protective eyewear is essential for the surgical team and for the patient and any observer in the treatment area. These should be stored close at hand. Each of these steps should become routine so that the laser use becomes seamlessly integrated into any patient care where it's needed.

What's the quality of construction?

All of the units are manufactured for patient care with necessary industrial standards that regulate not only electrically powered devices but also dictate infection control requirements. The quality of construction on every laser should be very high, although some components will wear with normal use. A main concern of the practitioner is likely to be how comfortable the delivery system is to handle. Some devices have small flexible optical glass fibers, while other lasers have larger hollow tube assemblies. All terminate in a handpiece and some have small tips or tubes to direct the beam toward the target tissue. Your hand should not fatigue while performing lengthy procedures and the handpiece should be able to reach in all the areas of the mouth. You should be able to perform the range of clinical procedures desired with ease and precision.

What are the safety features?

All dental lasers are well equipped with built-in safety features subject to rigorous rules. Some examples of these features are an emergency stop button, emission port shutters to prevent laser emission until the correct delivery system is attached, covered foot switch to prevent accidental operation, an adjustable control panel to ensure correct emission parameters, audible or visual signs of laser emission, locked unit panels to prevent unauthorized access to internal components, key or password protection, and remote interlocks to minimize the risk of accidental exposure. Clearly, the practitioner must be familiar with these protective items, and a laser safety officer must be appointed to supervise the laser's operation.

What is the cost of operation?

Aside from the initial investment of the device, each procedure will have a cost while performing a procedure. Some items or accessories are single use. An example is a tip for a diode laser; these tips are available in multiple diameters and lengths. One tip can generally be used for one patient visit, although treatment of multiple areas may require more than one tip. Other components are designed as long lasting, but could require replacement. An example is the delivery system itself. Optical fibers can lose some transmissive capability over time; some handpieces have mirrors or other components that

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degrade. Protective glasses can be scratched or damaged from repeated use. On the other hand, the active medium of the laser and other internal parts generally show little or no wear throughout the life of the laser. While the tip cost is a small percentage of the fee, other items can be a significant economic factor for the practice. In every case, the manufacturer should be able to service the unit and offer replacement parts when necessary.

How are the parts sterilized or disinfected?

It is extremely important to follow the manufacturer's instructions for infection control to prevent any cross contamination from patient to patient. Some components of a laser, especially those that are in direct contact with oral tissues, are either autoclavable or disposable. The handpiece is an example of the former, and the single use tips are disposable. Other areas like the control panel and the delivery system can be protected with barriers and subsequently disinfected with standard spray on liquids. The protective safety glasses can also be disinfected.

1.3 Integrating a Laser into Your Practice

Lasers have provided a new cutting-edge technology to the dental world. It is truly amazing to think about how such an investment like this could have such a huge impact on clinical practice. Incorporating lasers into conventional therapies helps in better prognosis and treatment outcomes. Lasers began as alternatives for soft tissue oral surgery and have expanded into all aspects of dentistry: orthodontics, endodontics, oral and maxillofacial surgery, periodontics, aesthetic dentistry, restorative dentistry, prosthodontics, dental implantology, and pediatric dentistry. In addition, low-level lasers can be used as adjuncts to treat chronic pathologies and within photodynamic therapy to treat infectious disease.

Several factors are presented for consideration about how a laser can be incorporated into a practice:

- *Identify your practice*. The first and perhaps foremost concept before buying a laser is to identify how you practice. Your treatment planning is based on the patient's oral health conditions, and the goals of your care will help improve or maintain that health as well as meet their expectations. Your clinical experience and scope of practice usually determine which procedures you perform, and a list of those should be studied so that you can begin to choose a laser instrument. Likewise, you may have thought about the addition of other newer treatments that will expand your services. Those could affect the type of laser you purchase.
- *Analyze what procedures do you currently perform that can be assisted with laser technology*. A dental laser can help you provide a higher level of care. In restorative dental procedures, management of soft tissue is

simplified because the tedious and painful placement of retraction cord can be eliminated. Better impressions are possible for indirect restorations such as crowns and bridges, and clearer margins near the gingiva are revealed for optical scanning. Class V carious lesions can be prepared at or near the subgingival level with excellent hemostasis. This ensures an improved bond for composite materials and ultimately results in better aesthetics and a longer-lasting restoration. Two minutes of disinfection treatment of an aphthous ulcer brings immediate relief to the patient who may have been suffering for days. Excellent hemostasis can be achieved during minor surgical procedures like an immediate loading implant or second-stage implant uncovering.

- Not only is there a clean dry operating site, but the improved visualization will save time for the other steps of the treatment. All this will save your time. Also, by differentiating your practice, you'll attract a more educated cliental. Patients associate laser procedures as less invasive leading to a better overall dental experience and once treated will refer their families and friends. There is easy return of investment as the procedures are made simpler and easier.
- *Think about which procedures that you do not perform that you would like to provide if you had a laser*. Within your scope of practice, there are procedures that can be accomplished with dental lasers in your office that you previously may have referred to a specialist and/or did not offer to your patients. Of course, proper training is necessary before you begin any procedure and is especially important when you are attempting a new one. However, understanding the fundamentals of the wavelength and watching the interaction as it happens will provide clinical experience and confidence for the clinician to continue offer additional treatment options at chairside. Endodontic therapy can be aided by both laser debridement and pathogen reduction. Examples of laser soft tissue excisions are numerous: a removal of fibrous tissue in an irritation fibroma and epulis in the soft tissues of patients wearing removable prosthodontic appliances, operculectomy treatment of an unerupted tooth, a frenectomy to prevent further adult periodontal problems, releasing a tongue tie in infants, and revising the frenum in a child's diastema to aid proper tooth positioning. Oral surgical procedures such as oral sub-mucositis fibrosis, lichen planus, and leukoplakia can also be performed. Lasers can also be used for aesthetic enhancement of the patient's smile by minor recontouring of gingival tissue, laser tooth whitening, and removal of depigmentation in the soft tissues. Osseous crown lengthening for treatment of altered passive eruption or to obtain adequate tooth structure for a restoration can proceed with the all-tissue lasers [4]. During the initial alignment phase of orthodontic treatment, low-level laser therapy (LLLT) can be given to patient as it has shown to accelerate the tooth movement and also to relieve the discomfort that occurred during the initial arch-wire changes [5]. That same effect, also known as photobiomodulation, can be used in patients with bruxism, temporomandibular joint disease, acute abscess areas, and many more applications [6]. One of the biggest hurdles while taking diagnostic records, impression making, or intraoral radiographs is gag reflex, which can be particularly strong in some patients. Low-level lasers are a boon in such cases; using lower doses of laser energy helps in minimizing the reflex [7]. When all these benefits are explained in detail, there is no doubt the patient will accept the planned treatment. The increased revenue also helps to satisfy a further return on the initial cost of the laser.
- *There are several choices of laser instruments*. There are many lasers available for purchase. Their availability can be dependent on regional regulations of sales and clearances, along with support of service and training. There are worldwide standard and consistent classifications so that basic choices can be made. A generic division describes dental lasers as either surgical or nonsurgical, and they are sometimes termed high level and low level, respectively. ▪ Figure 1.1 shows a simple flowchart of the basic categories of those classifications.

After analyzing your practice's procedures, you can become familiar with how each available laser could be utilized.

- *Prioritize your clinical needs with respect to how a laser's use would be of benefit*.
  - In a modern dental office, a patient has certain expectations: treatment should be less painful, more precise, and less invasive with less bleeding, better healing, and fewer appointments. Fortunately, the practice of dentistry has been revolutionized and modernized so that our procedures have become more patient friendly. With the incorporation of this device, an anxious patient feels more confident, and there is noise-free or no vibration of the drill or smell of conventional dental care, with the fact that much of the treatment can be performed with «no anesthesia» or «needle-free» dentistry. These factors could transform patients who were resistant to conventional treatment into ones who readily accept treatment. Also in the future, we can expect more referrals to the practice, thus, proving lasers to be a safe investment and a true value for the money.

If your practice is focused on oral hygiene maintenance (sulcular debridement), prosthodontic or restorative tissue management (gingival troughing), or aesthetic procedures (crown recontouring, gingivectomy, gingival depigmentation, and laser whitening), a diode or a Nd:YAG laser would be ideal. The small-diameter fiber optic contact delivery can be safely used on soft tissue with minimal interaction with hard tissue. For the restorative practice and conservative dentistry, the erbium family (Er,Cr:YSGG, 2780 nm, and Er:YAG, 2940 nm) and the 9300 nm carbon dioxide lasers offer a wonderful alternative and adjunct to the dental bur. A specialty practice that is mainly focused on oral and maxillofacial surgical

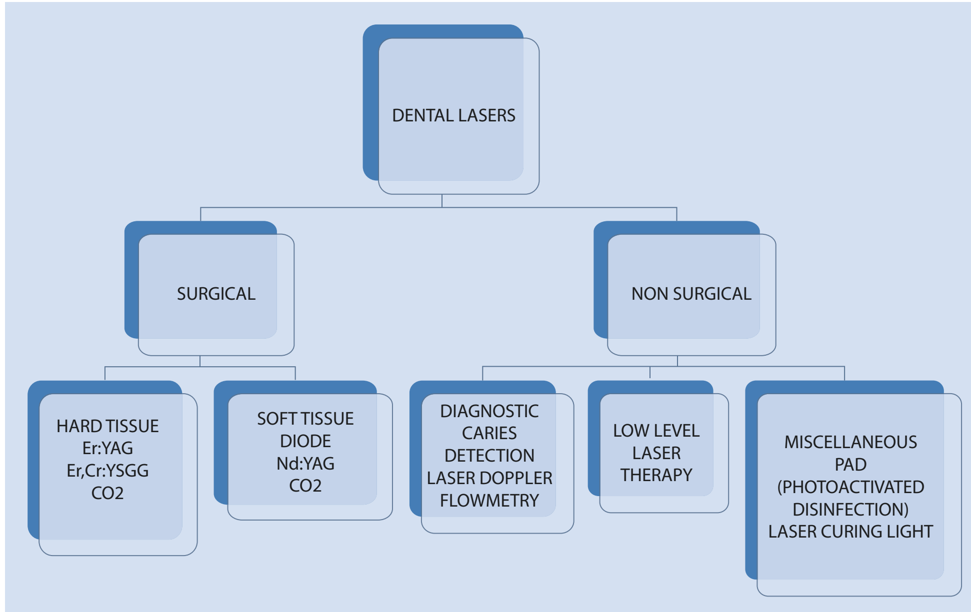


Fig. 1.1 A graphic representation of the type of dental lasers. The surgical lasers have output power sufficient for incision, excision, ablation, and coagulation of dental tissues, whereas the nonsurgical lasers will not perform those procedures. A few surgical devices do have capabilities for low-level laser therapy

procedures, or periodontal surgery, the aforementioned tooth cutting lasers perform osseous surgery safely and rapidly while minimizing potential thermal damage to adjacent tissues and the blood supply. In addition to those instruments, the 10,600 nm carbon dioxide laser is often used for precise and rapid cutting during soft tissue surgery.

The clinician is constantly assessing and assimilating patient's needs and satisfaction while deciding on the proper treatment [8]. When choosing to add a laser to the procedure's protocol, certain wavelengths have advantages over others. To be clear, any of the available laser wavelengths are suitable for soft tissue treatment. But if the dentist treats both soft and hard tissues, only the erbium or the 9300 nm carbon dioxide instruments will provide necessary energy and tissue interaction for those dental procedures.

- *There is no single perfect laser wavelength*. Currently there are over two dozen indications for the use of the various dental wavelengths, as listed in the different manufacturer's operating manuals. There are often many discussions in the profession about which laser is the best, as well as debates about how all lasers are the same. It should be clear that although similarities exist, every laser wavelength has some unique properties compared to another. When asked the question about which laser is best, a proper answer could be the one you know how to use in your practice!

One thing which must not be forgotten is that there is «no perfect laser.» It is simply because the absorption characteristics of the photonic emission by a particular wavelength are different for the same tissues. Although every laser can be used for soft tissue surgery, a very fibrous area will be difficult to cut with a diode laser but will be easily incised with carbon dioxide. On the other hand, a diode can perform aesthetic contouring of gingiva adjacent to a natural tooth without interacting with the healthy enamel, but the carbon dioxide wavelength could damage that same enamel. Erbium lasers are very highly absorbed by water, which allows the easy removal of a carious lesion. However, highly fluoridated enamel can be more challenging to ablate because of the minimal water content. In addition, the laser's output can be a factor during treatment. Some procedures need only minimum energy levels; an example would be when desensitizing an aphthous ulcer. Likewise, photobiomodulation effects are performed at power densities well below any threshold of surgical cutting. In contrast, tooth preparation requires very high peak powers and very short pulses for efficient removal of the mineralized material without thermal damage.

Therefore, before investing, all of the factors just discussed should help the clinician to identify what kind of laser is best suited for one's practice.

1.4 Sales, Training, and Company Support

The laser manufacturer is engaged in a highly competitive business with a limited market of purchasers. The sales team must be transparent and honest about their product's performance and avoid unrealistic assurances about everything from clinical efficacy to availability and shipping time for the device. The company's representatives should have a sound knowledge of the laser's operation so that they can initially demonstrate how the laser is set up along with knowing how to help in case of troubleshooting a problem. Customer support representatives should be available to answer questions and solve problems.

Training and continuing education opportunities must be available. Some companies have formed institutes that provide training for basic and advanced procedures, along with such features as educational resources, a discussion forum, examples of clinical cases, and other digital learning. Others sponsor courses and workshops during larger dental conferences.

It would be useful to know how long the particular device has been commercially available for purchase as well as to learn about the company's track record of efficiency, reliability, and service. Some companies have a global market, but local support in your country or state would be very desirable. Regional dental suppliers can also represent the company to provide sales and service. Since those suppliers already have a relationship with the dental practice, this could facilitate good support.

The operating manual enclosed with the laser is the guidebook for its use and describes the clinical procedures for which the device may be used. This is sometimes termed «indication for use» and simply means that there is solid evidence for safety and effectiveness, as opposed to «off-label» treatment. All sections should be well written. Instructions should include the range of operating parameters for each procedure for the wavelength's use. Those settings are always guidelines and suggestions for modification should be listed. Factors such as beam diameter versus output power, approximate time of exposure, and varying tissue interaction must be considered. The steps necessary for the assembly and disassembly of the delivery system should describe every detail. The care and maintenance of each component of the laser should be illustrated. Warnings, precautions, and troubleshooting procedures should be explained, along with contact information for support.

As previously mentioned, there are various accessories necessary for using a laser. These include delivery system tips, foot control pedals, keys, interlocks, and protective eyewear. The initial and replacement cost of these items as well as any maintenance and availability should be noted. In some cases, accessories are optional and have additional costs. Those can negate an initial attractive initial price of the laser itself. Likewise maintenance can be included for a period of time in the purchase, but a contract for service beyond that may incur a fee.

The warranty period should be clearly stated, and the dentist purchaser should thoroughly understand the terms and conditions. Lasers are designed for precision delivery of photonic energy, and the device is generally well constructed. However, any portion can be damaged with normal use and accidental breakage can occur. Warranty is a promise provided by the manufacturer to repair or replace the instrument if necessary within a specified time. That promise may stipulate what repairs are covered in specific circumstances.

The laser's operation is governed by software control of the internal components. Many companies offer updated versions of their software and may include them in the purchase price. Likewise some of the hardware may undergo modification, and it would be prudent to determine if any retrofitting or upgrades are appropriate and available for the model of laser purchased.

1.5 Education and Knowledge

A prudent question to ask is «how much training and do I need?» The simple answer is that you should continue to acquire knowledge all during your dental career. The elusive secret to success has always been to achieve better quality of patient care. That achievement can only be found with lifelong learning. It starts with the sessions offered by the laser manufacturer after purchase. Unfortunately some of these are simply didactic lectures available on playback media. Hands-on simulated exercises on animal tissue followed by over-the-shoulder supervised patient care are very superior learning methods. Whichever methods of initial training are taken, simple procedures performed with minimum power settings will help to overcome your fears and increase the level of your skills. Observing the rate of tissue interaction and the progress of reaching the treatment objective may appear to be at a slower pace than you first expected. Your patience will be rewarded; in fact, a slow sweeping motion for tissue removal is usually preferred. Moreover, you will avoid unnecessary thermal damage while precisely cutting and contouring tissue; and that will produce a successful outcome. That continuing journey toward mastering how a procedure is performed can bring you a lot of satisfaction. During that time, your range of comfort with all procedures will certainly increase.

For continuing education about the use of lasers in dentistry, a number of opportunities are available. Local study clubs and regional academies have regularly scheduled meetings where members can share information. Many major dental conferences feature presentations and workshop courses. There are university-affiliated programs which both offer information and assess competency. Advanced programs, fellowship, mastership, and MSc programs are offered in many countries. A document entitled «Curriculum Guidelines and Standards for Dental Laser Education» was developed in 1993 and is often used as a reference for these learning opportunities [9].

Finding a mentor would be a bonus for any laser clinician. There's no faster way to improve your skills and knowledge than to have someone to guide you as you work on your goals. That person should have the right attitude about teaching along with the experience to demonstrate the proper way to perform the procedure while correcting any of your deficiencies. Your confidence in delivering care will also increase. In addition, you can gain insights about new techniques and treatments.

Another question that can be asked is «what are the rules for laser use?» The response is that various regulatory agencies exist to ensure safe and efficacious use of lasers for the health and welfare of patients. The practitioner must have knowledge of those regulations and comply with their provisions. A review of those is presented here and will be detailed in ▶ Chap. 5 on laser safety.

- Regional or local bodies issue a license to practice dentistry to a properly qualified dentist. That award allows the dentist to offer dental care according to the scope of practice—i.e., the general or specialty services that are provided. That care is delivered in a manner that is based on the practitioner's training, education, and clinical experience. It should be remembered that «laser dentistry» is not a recognized specialty; in contrast it is a description of using an instrument during a procedure.
- Certain agencies control the manufacturer and their products, but do not control the practice of dentistry. One example is the US Food and Drug Administration through its Center for Devices and Radiological Health that regulates the construction of the laser to ensure compliance with medical device legislation. That same agency awards the manufacturer a marketing clearance for a procedure which states that the treatment where the laser is used will be safe and effective.
- The International Electrotechnical Commission prepares and publishes international standards for all electrical, electronic, and related technologies that include regulations and conformity assessment for lasers in a similar manner to the Food and Drug Administration.
- Both of these organizations strongly influence regulatory agencies in other countries.
- Currently there is no common agreement about what defines a proper credential for a dental laser practitioner. Some local licensing jurisdictions have a course requirement. A small number of dental schools have introduced laser care into the predoctoral curriculum.

Evidence-based dental practice comprises an equal combination of the integration of clinically relevant scientific evidence, the clinician's experience, and the patient's treatment needs and experience. Regarding dental lasers, the peer-reviewed literature offers an abundance of studies, clinical cases, and meta-analysis. Some reviews proclaim controversies that exist with regard to superiority of incorporating lasers into the treatment protocol. However, many manuscripts using controlled clinical studies do show effectiveness of these instruments. The laser practitioner should be familiar with as much of the literature, published articles, case reports, and scientific reviews that are readily available online or offline. Less reliable blogs and forums can offer information and networking about personal experiences. All of those resources contribute to evidence that has a place in the hierarchy of learning. The knowledge of how a particular wavelength would serve the purpose will be very beneficial to the success of your practice.

1.6 Investing in Your Team

Nurturing your employees is an important part of creating an engaged workforce. Invest in their personal and professional development and it will pay handsome dividends down the line by giving you a happy, capable, and productive team in an optimized practice. Your patients will immediately notice the professional and friendly atmosphere where you have created a healthy working environment with a caring and holistic approach toward their treatment.

Everyone on your staff from the receptionist and administrators at the front desk to the clinical team of assistants, hygienists, and other associated doctors must be educated about dental lasers.

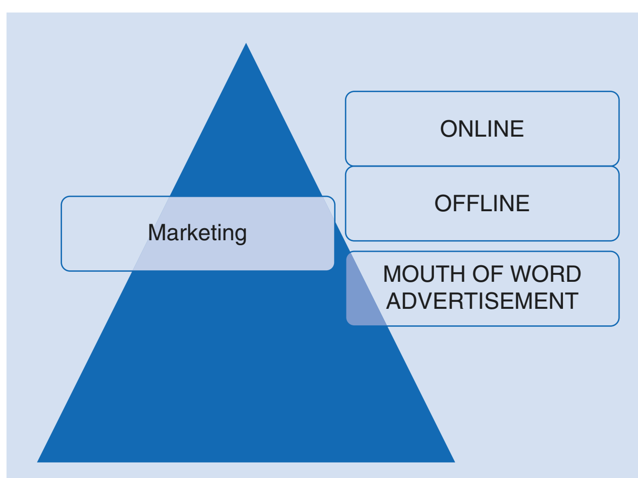
With proper training and experience, they can answer any of the patient inquiries about how a laser might be used for treatment. They can increase the patients' awareness of the advantages and limitations of the technology. They can also address any apprehension about a procedure. Interestingly, many people are familiar with lasers because of previous medical procedures; and a few have expressed a misunderstanding about the word radiation as it represents the last letter in the laser acronym. Regarding the latter, a well-informed staff member can clarify the fact that dental lasers do indeed emit radiation in the thermal portion of the electromagnetic spectrum and not in the ionizing portion used for radiographs. The entire team would benefit by attending an introductory course about the use of lasers in dentistry as well as being actively interested in other continuing education offerings.

1.7 Marketing

One of the secrets to a successful practice lies in its marketing. Marketing is a process by which a product or service is introduced and promoted to potential customers [10]. It is the best means to make people aware of the quality of service being provided. The overall marketing umbrella covers advertising, public relations, promotions, and sales.

There are mainly three methods of marketing, namely, online, offline, and word of mouth. The latter is sometimes termed «internal marketing.» Online marketing uses the Internet, e-mail, social networking websites, and blogs as online channels for delivering marketing content to the public. Offline marketing is disseminated through the «conventional» media: radio, television, and print ads. Word-of-mouth marketing is the best of the three approaches for any dental office. The starting point is that the staff or team must have knowledge of the practice. A written strategic plan composed of a vision, mission statement, goals, and objectives will certainly provide a framework for that knowledge. Each employee should be able to articulate the fact that the entire office constantly stays updated with current innovations and procures the latest technology to ensure the best treatment, care, in a comfortable environment. That in turn will clearly influence how the patient will speak about the practice, encouraging friends, neighbors, and relatives to seek dental care there.

For the best results, all three modalities should be incorporated in a marketing plan. For the first two portions, you also may consider promoters, publicists, and professional marketing outlets to support any of your large-scale promotion efforts. Obviously, a budget must be prepared so that the dollars necessary for any of the above are well spent. However, word-of-mouth marketing usually just involves spending some time inside the office to ensure a consistent and high standard of delivery of dental care.



Lasers can be an excellent marketing tool. In a surgical case, the dentist who utilizes a laser is no longer bound by conventional treatment that always involves injectable anesthesia, along with bleeding, and sutures. Instead the patient can be treated with the alternate laser technique that may require minimal or no anesthesia, with no bleeding, and minimal to no suturing. Similarly, for restorative dentistry, the traditional cavity preparation with rotary high- and low-speed drills and burs can give way to laser ablation of the carious lesion and preparation of the preparation margins. As an additional benefit, some of the treatment can be also performed with less anesthesia and more patient comfort.

Patients are becoming more techno-savvy these days, and because of that, they can spend an inordinate amount of time researching dental treatment options on various online portals with varying degrees of opinion and education. Nonetheless, they gain knowledge about their options; and they rarely oppose treatments with laser if given a choice. They know and understand that the technology is up to date and it can provide faster, more comfortable dental care while achieving those better results in less time.

1.8 Why Lasers in Dentistry

Lasers are in common use in every aspect of our lives, be it military, industrial, or medical. Now in its third decade, laser dentistry is no exception. The term laser itself evokes a positive response in patient's mind. Possibly because of prior experience with other medical procedures, the patient will associate the treatment performed with the instrument as very beneficial. Laser dental care can be quicker and more efficient along with markedly reduced pain, lack of bleeding, minimal need of anesthesia, and last but not the least minimal postoperative discomfort. The patients can resume their daily activities shortly after the treatment is rendered [11].

Why should I buy a laser?

The dental laser should become part of the practitioner's armamentarium. The photonic energy, with its unique properties of monochromatism and coherency, transmitted through an ergonomic delivery system, becomes a novel instrument for dental care. When used with proper knowledge, understanding, and correct training, it can function as an integral part of any dental treatment appointment. The clinician can have assurance that each laser procedure is being safely and easily performed without some of the disadvantages that were present when the scalpel or electrosurgery was used. Two examples can be listed: disinfection during a laser incision versus a bleeding scalpel cut and safe removal of tissue during laser implant fixture exposure versus certain damage with an electrosurgical tip. In addition, for those who challenge themselves to constantly better their skills, a laser is a must «have» for them—not as a «gadget,» but as a surgical instrument.

What difference will it make for my patients and myself?

The incorporation of technology in dentistry has improved the way we serve our patients. Digitized radiographs are replacing traditional radiographs, diagnosis is done on 3D model of teeth and bone (CBCT) and single sitting root canals, and CAD/CAM technology is gaining popularity. All these advancements including lasers are being incorporated to improving the dental care provided to the patients on daily basis [12]. Dental pain is scored among the world's first ten phobias. In some patients, just the sight of dental chair, the whining noise of air rotor, or the white coat of a dentist can create panic attacks. Dental lasers make a huge difference in the life of such patients since they can reduce the level of stress and anxiety [13] and help a clinician to deliver the best of dentistry. As an added benefit, it has been shown that lasers can help to provide neural blockage leading to analgesic effect and anti-inflammatory effects [14].

Will it be income generating?

Dental lasers can help the practitioner to formulate treatment plans for the benefit of the patients. As mentioned previously, the existing procedures will be improved and new or previously referred treatments can be offered. The dentist may necessarily increase the fee schedule to reflect the additional cost of the laser purchase, but that adjustment should be explained by simply enumerating the benefits of using the instrument.

The surgical procedures are generally shorter than traditional surgeries and are usually performed on an outpatient basis. Patients usually have less pain, swelling, and scarring than with traditional surgeries. This makes a huge difference in the quality of life of patient since there is usually no long recovery period. Just as important, the practitioner can be more efficient because the surgical appointment and necessary pre- and post-procedure protocol is less complex and time consuming. Thus there could be more time available for other patients which will in turn generate more revenue and help to grow the practice. An additional advantage is that multiple procedures may be performed during one visit, thus increasing production. It naturally follows that more patient's acceptance of a proposed treatment, coupled with a positive, comfortable, and healthy outcome, will result in confident referrals of new patients to the practice.

When should a laser be used?

The clinician should know the indications for the use of the laser. This textbook will describe all of those in detail. Continuing education will certainly provide suggested techniques and protocols. When reviewing the steps necessary for a procedure, there should be an analysis of how the laser could be used either as an adjunct or as monotherapy. Equally importantly, the instrument and all of the needed accessories should be easily obtained—within reach or stored close by—so that it can be inserted into the procedure. As the clinician continues to utilize the laser, it will become essential in the armamentarium. For some treatments, it can be substituted for other instruments; in other procedures, it can be used adjunctively. Likewise, the experience of repeated use will result in confidence in delivering excellent patient care. Indeed, the laser will become the smart investment that was hoped for during purchase. Figure 1.2 shows a small sampling of clinical procedures where a laser can be used. In every case depicted, the laser was used instead of conventional instrumentation.

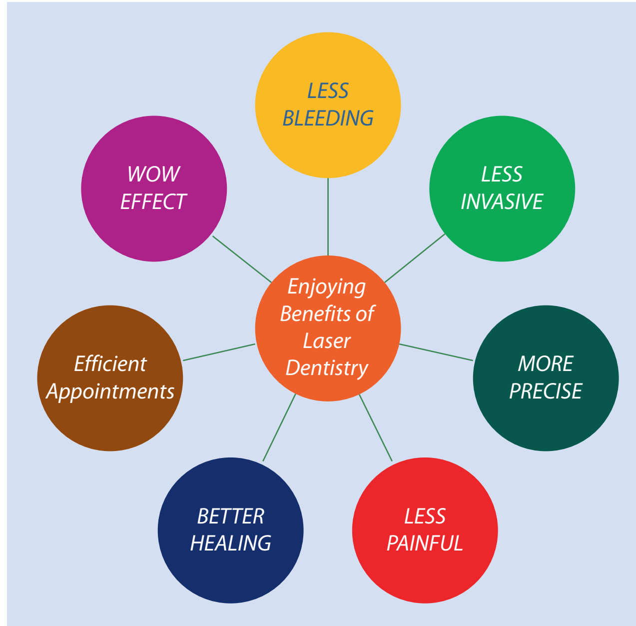
Fig. 1.2 **a** Preoperative view of hyperplastic tissue present during orthodontic therapy. **b** Postoperative view showing tissue removal, with more normal periodontium. **c** A preoperative view of a wide maxillary diastema with frenum involvement. **d** Photo depicting the healed frenum revision, gingivectomy, and good progression of orthodontic alignment. **e** A low-level laser is used for treatment of temporomandibular joint inflammation. **f** Preoperative view of interproximal carious lesions. **g** Immediate postoperative view of the new restorations. Both teeth were prepared with the laser instead of the dental handpiece. **h** Preoperative view of pigmentation on the mucosa. **i** Postoperative view showing the pigment removed. **j** Preoperative view of a benign irritation fibroma. **k** Postoperative view showing healed area

1.9 Limitations of Laser Dentistry

If you are a proficient clinician using a laser, then you can see the almost limitless and enormous possibilities of using them for treatment. However, as with any instrumentation, certain considerations apply. The clinician should be very well trained to judge the disease to be treated. After proper selection of the case, an appropriate decision is to be made on what wavelength, power, or energy density will be used and will be dependent on the absorptive pattern of the target tissue. This of course implies a very thorough understanding of the fundamentals of laser physics, tissue interactions, and the safe use of the device.

There are some disadvantages to the currently available dental laser instruments. They are relatively high cost and require training. Most of the laser emission tips are end-cutting, although there are some radial firing ones available. Nonetheless, a majority of dental instruments are both side- and end-cutting. The laser practitioner will be necessarily required to employ a modification of clinical technique. A laser incision is by definition not as sharp edged as the one made with a scalpel. Furthermore, since sutures are seldom used compared to the one from a surgical blade, a laser wound heals by secondary intention. The patient must be given the appropriate postoperative instructions to correctly care for the area during healing. As mentioned, no single wavelength will optimally treat all dental disease. Accessibility to the surgical area can sometimes be a problem with some current delivery systems, and the clinician must prevent overheating the tissue while attempting to complete a procedure. One additional drawback of the erbium family and 9300 nm carbon dioxide lasers is the inability to remove defective metallic and cast porcelain restorations. Of course, this limitation in some cases could be quite beneficial when treating small areas of recurrent decay around otherwise sound restorations. Sometimes the slower pace of laser soft tissue surgery can lead to tissue charring or carbonization during any surgical procedure. This can be due to a combination of too much average power or moving the laser beam too slowly. Both of those can be corrected with experience. One aspect that should not be ignored is the production of the laser plume which is a by-product of vaporized water (steam), carbon and other harmful molecular particles, and possibly infectious cellular products, which combine to produce a malodorous scent. Maintaining the suction wand within 4 cm of the surgical site to remove as much of the plume as possible is recommended [15, 16].

1.10 Enjoying Benefits of Laser Dentistry



Over the time, the developments in the art and science of dentistry have provided us with the ability to allow the clinician to provide minimally invasive solutions to the patient's disease. From the incorporation of less invasive treatment of periodontitis to comprehensive cosmetic restorative treatment, the current standard is to conserve as much of the dentition and surrounding structure as possible. With the advancements in innovative materials and new and improved clinical techniques, that goal can be achieved. The rapid use of laser technology has gained popularity in various dental specialties and disciplines including endodontics, prosthodontics, oral and maxillofacial surgery, orthodontics, dental implantology, pediatric dentistry, aesthetic dentistry, and periodontics. It has revolutionized some treatment protocols and is certainly a practice-building tool.

The benefits enumerated above can transform a patient who was previously resistant to conventional treatment plans into a more relaxed and certainly cooperative one. Moreover, the fact is that dental practice can be very physically demanding and stressful during normal patient care. For more special needs patients such as those who are mentally and physically challenged, it is possible for the laser clinician to perform more procedures with efficiency and confidence, while conserving time and respecting the patient's tolerance. Lasers are especially helpful in geriatric patients as it makes the procedure more tolerable and help them overcome some of the barriers in providing dental care to them including severe dental complexity, multiple medical conditions, and diminished functional status. Similarly, laser-assisted pediatric dental treatment can result in a happy, healthy, and trusting child whose parents will appreciate the gentle and efficient care.

In today's digital world, patients interact almost instantly with their multimedia friends, share their experiences and concerns, and better understand diagnoses and treatment options. They are more likely to accept recommendations for treatment, and they certainly are willing to invest in a procedure that they value and that is as comfortable as possible. If a patient's experiences with the laser are positive, then it will invite more referrals. In short, lasers can enable the dentist to render better quality dentistry [17].

Conclusion

We live in a fast-paced world. The practice of dentistry is constantly evolving and there are mainly two main reasons we change: one is that we want to strive to deliver the optimum treatment available for our patients; the other is that we want to keep abreast with the latest and best method to achieve that. Never stop learning or else we shall stop growing. In the present era, it is always important to improve your skills and abilities, and we should continue to learn so that we can continue to grow in knowledge as a lifelong pursuit. Willingness and openness to learn new things is the key to success. Whenever we think we are good, we can be even better.

The first step toward laser dentistry is to seek objective information on all aspects of the instrument and its uses. Eventually, the decision to purchase a laser should be based on sound scientific evidence; your own experience, knowledge, and training; and upon the patient's preference for treatment options.

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Laser and Light Fundamentals

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2

Core Message

The word LASER is an acronym for light amplification by stimulated emission of radiation. The theory was postulated by Albert Einstein in 1916. A brief description of each of those five words will begin to explain the unique qualities of a laser instrument.

Once the laser beam is created, it is delivered to the target tissue. Furthermore, each device has certain controls that the clinician can operate during the procedure.

An understanding of these fundamentals will become the foundation for further elaboration of the basic concepts of how lasers are used in dentistry.

2.1 Light

2.1.1 Origins and Curiosities of Light

The word light has been used for many centuries, including biblical references such as in the beginning sentences of the Book of Genesis. Early civilization seemed to understand that the cycle of day and night with the sun, the moon, and the stars produced differences in ambient brightness. Historical investigations into the nature of light produced interesting and sometimes conflicting studies. Ancient peoples were curious about this brightness: the Greek philosopher, Pythagoras, began to develop wave equations about 400 B.C. Over a century later, the Greek mathematician Euclid claimed that light is emitted in rays from the eye; he then proclaimed the law of reflection of those waves. It took until 1021 for a mathematician from Basra, Ibn al-Haytham, to correct the concept and prove that light enters rather than emanates from the eye. In addition, al-Haytham postulated that there are tiny particles of energy coming from the Sun that produce light. In 1672, British physicist Isaac Newton was studying the laws of reflection and refraction and concluded that light was made of particles, which he called «corpuscles» [1]. He concluded that light is a combination of seven colored particles—violet, indigo, blue, green, yellow, orange, and red (in keeping with the belief that seven is a mystical number.) Those particles combine to produce white light [2]. A few years later in 1678, the Dutch physicist Christiaan Huygens insisted that light was made up only of waves and published the «Huygens» Principle [3]. As history would have it, both Newton and Huygens were at best half correct.

Over a hundred years later, new discoveries of light emerged. In 1800, William Herschel, a German-born musician and astronomer, moved to England and investigated individual temperatures of the visible colors. From those experiments, he discovered infrared light [4]. Johann Ritter, from a region of Eastern Europe now known as Poland, discovered ultraviolet light in 1801, by observing how the common chemical silver chloride changes color when exposed to sunlight [5]. The British physicist Michael Faraday produced evidence that light and electromagnetism were related [6]. In 1865 his Scottish colleague James Maxwell then explained electromagnetic radiation: that is, electricity, magnetism, and light are in fact interrelated in the same phenomenon [7]. His discovery quantified the different wavelengths of radiation and thus helped to explain our current understanding of the existence of light in more than just the visible spectrum of Newton's colors. In 1895 Wilhelm Roentgen, a German professor of physics, added X-radiation to the electromagnetic spectrum, after studying many experiments from colleagues such as Philipp Lenard and Nikola Tesla [8]. He used the terminology of X to signify an unknown quantity. A theoretical physicist Max Planck, also from Germany, proposed that light energy is emitted in packets he termed quanta in 1900 [9]. He formulated an equation that gave a relationship between energy and wavelength or frequency. In 1905 the German scientist Albert Einstein discovered what he termed the photoelectric effect. He observed that shining light on many metals causes them to emit electrons, and he termed them photoelectrons. He then deduced that the beam of light is not just a wave traveling through space but must also be composed of discrete packets of energy, as described by Planck. Einstein called these tiny particles photons [10], thus crystallizing the particle-wave dual nature of light.

2.1.2 The Duality of Light

Based on the discoveries and arguments over the last three millennia, it can now be stated that light is a form of electromagnetic energy with a dual nature. It behaves as a particle and travels in waves at a constant velocity. The basic packet or quantum of this particle of radiant energy is called a photon [11]; a photon is a stable particle that only exists when moving at the speed of light in a vacuum. By implication of the theory of relativity, it has no mass. When decelerated, it no longer exists, and its energy is transformed.

The wave of photons which travels at the speed of light can be defined by two basic properties, as shown in Fig. 2.1. The first is amplitude, which is defined the vertical height of the wave oscillation from the zero axis to its peak. This

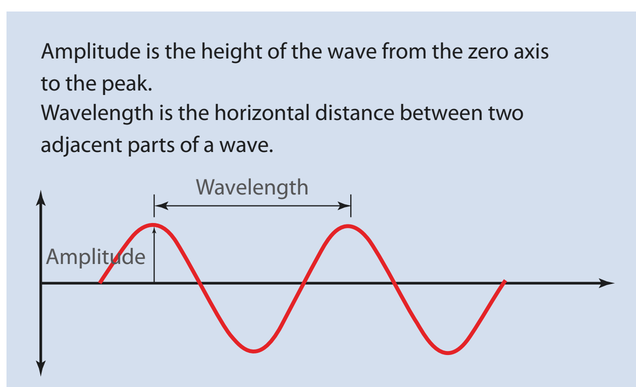


Fig. 2.1 A depiction of electromagnetic waves showing the two important quantities of amplitude and wavelength

correlates to the amount of energy carried in the wave: the larger the amplitude, the greater the amount of energy available that can do useful work. The second property of a wave is wavelength, which is the horizontal distance between any two corresponding points on the wave. This measurement is very important both in respect to how the laser energy is delivered to the tissue and what the interaction will be. Wavelength is measured in meters, and dental lasers have wavelengths on the order of much smaller units using terminology of either nanometers (10^{-9} m) or microns (10^{-6} m.) As waves travel, they oscillate several times per second, which is termed frequency. Frequency is inversely proportional to wavelength: the shorter the wavelength, the higher the frequency and vice versa.

2.1.3 Properties of Light and Laser Energy

Ordinary light produced by a table lamp, as an example, is usually a white glow. The white color seen by the human eye is really a sum of the many colors of the visible spectrum—for example: red, orange, yellow, green, blue, and violet, as first described by Isaac Newton. The light is usually diffuse, and not well focused.

Laser energy is distinguished from ordinary light by two properties. One is *monochromaticity* which means the generated light wave is a single specific color. For dental instruments, that color is usually invisible to our eyes. Secondly, each wave has *coherency*, identical in physical size and shape along its axis, producing a specific form of electromagnetic energy. This wave is characterized by spatial coherency—that is, the beam can be well defined; the beam's intensity and amplitude follow the Gaussian beam's bell curve in that most of the energy is in the center, with rapid drop-off at the edges. There is also temporal coherency, meaning that the single wavelength's emission has identical oscillations over a time period. The final laser beam begins in collimated form and can be emitted over a long distance in that fashion. However, beams emanating from optical fibers usually diverge at the tip. By using lenses, all the beams can be precisely focused, and this monochromatic, coherent beam of light energy can accomplish the treatment objective.

Using a household fixture as an example, a 100-watt lamp will produce a moderate amount of light and proportionally more heat in a room. On the other hand, two watts of laser power can be used for a precise excision of an irritation fibroma, providing adequate hemostasis on the surgical site without disturbing the surrounding tissue.

2.2 Emission

2.2.1 Spontaneous Emission

In 1913, Niels Bohr, a Danish physicist, developed his model of an atom, applying the quantum principle of Planck. He proposed distinct energy orbits or levels of energy around the nucleus of that atom. Bohr found that an electron could «jump» to a higher (and unstable) level by absorbing a photon and then the electron would return to a lower (more stable) level while releasing a photon [12]. He termed this spontaneous emission. The nuance to this emission is that, since there are several possible orbital levels in the atom, the wavelength of the photonic emission would be determined by the energy of the emitted photon, according to Planck's equation. It should also be noted that the emitted photon will likely have a random direction and phase. In more simple terms, spontaneous emission can be demonstrated when a conventional electric light bulb is switched on. The filament glows brightly emitting light and heat as the electrons are excited to higher energy states and then return to their ground conditions. Different broad groups of wavelengths (e.g., white light) will be produced during emission from the higher energy levels. A light-emitting diode also produces spontaneous emitted light by using a flow of energized electrons recombining on the positive side of the wafer to produce luminescence. The color (wavelength) of the emitted light will depend on the chemical composition of the diode wafer [13].

2.2.2 Stimulated Emission

In 1916 Albert Einstein postulated the theory of lasers [14]. Using Bohr's model, he postulated that during the process of spontaneous emission, an additional photon, if present in the field of the already excited atom with the same excitation level, would stimulate a release of two quanta. These would be identical in phase, direction, and wavelength. In addition, these emission photons would share monochromatic and coherent properties—thus a laser is born.

2.3 Amplification

Amplification is part of a process that occurs inside the laser. Once stimulated emission occurs, the process should theoretically continue as more photons enter the field both to excite the atoms and to interact with the excited photons returning to their ground state. One could imagine a geometric progression of the number of emitted photons, and, at some point, a population inversion occurs, meaning that a majority of atoms are in the elevated rather than the resting state. As Bohr implied, there can be several potential levels of energy available in most atoms. Having multiple levels (more than two) would aid in maintaining a population inversion because there would be no possibility of equal rates of absorption back into the ground state and stimulated emission. This amplification effect can only occur if there is a constant and sufficient source of energy, which is supplied by a pumping mechanism.

2.4 Radiation

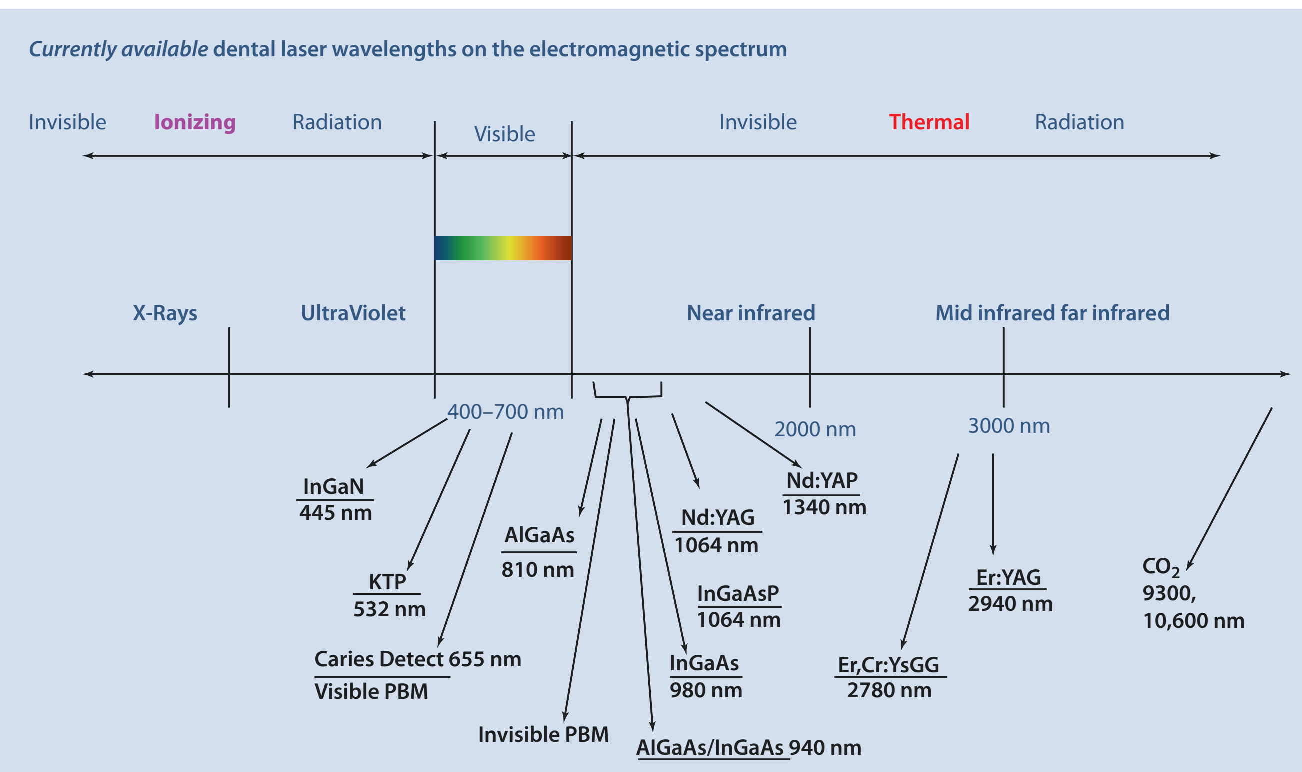
The basic properties of a wave were discussed in ▶ Sect. 2.1.2. The entire array of wave energy is described by the electromagnetic spectrum (ES)—in other words, all frequencies and wavelengths of radiation [15]. The ES has several regions with rough boundaries of wavelength or frequency. There are seven general classes, with increasing order of wavelength to describe the radiation: gamma rays, X-rays, ultraviolet radiation, visible radiation, infrared radiation, microwaves, and radiofrequency waves. These wavelengths range in size: gamma rays measure about 10^{-12} m; on the other end of the spectrum, radio waves have wavelengths up to thousands of meters. The ES can be more broadly divided into two divisions with gamma rays, X-rays, and ultraviolet light in a group termed ionizing radiation, while all the other wavelengths are termed nonionizing. Ionizing simply means that the radiant wave has enough photon energy to remove an electron from an atom, and those wavelengths can cause mutagenic changes in cellular DNA. The human eye responds to wavelengths from approximately 380–750 nm, with those two numbers representing deep violet and dark red, respectively. That range is termed the visible spectrum. The term thermal radiation can be applied to many wavelengths. For example, an infrared lamp generates heat; the sun provides both light and heat; and the ionization present in plasma can also produce high temperatures.

The energy of a photon can be calculated using the equation from Max Planck. It states that the energy is directly related to the frequency of wave or inversely proportional to the wavelength. Thus, gamma or X-radiation with very short wavelengths (ranging from 10^{-12} to 10^{-10} m) has very high energy, while radio waves (approximately 3 m to 1 km) have significantly lower energy by comparison.

2.5 Components of a Laser

Identifying the components of a laser instrument is useful in understanding how the energy is produced. For dentistry, there are two basic types of lasers: (1) one that operates as a semiconductor and is compact in size and (2) one that has distinct components that, when assembled, occupy a larger footprint. The first type is generally known as a diode laser; the second type encompasses all other lasers. Both of these types share common features—an active medium, a pumping mechanism, and a resonator. In addition, a cooling system, controls, and a delivery system complete the laser device.

All available dental laser devices have emission wavelengths of approximately 0.45 microns, or 450 nanometers to 10.6 microns or 10,600 nanometers. That places them in either the visible or the invisible nonionizing portion of the electromagnetic spectrum. ◘ Figure 2.2 is a graphic depiction of those lasers on a portion of the electromagnetic spectrum.



◘ **Fig. 2.2** A graphic showing the currently available dental wavelengths' position on the visible and invisible nonionizing portion of the electromagnetic spectrum. Note that most of the wavelengths also include the composition of the active medium which produces that wavelength. PBM is an abbreviation for photobiomodulation, and those instruments use various active media

2.5.1 Active Medium

Lasers are generically named for the material that is being stimulated; such material is called the active medium. As mentioned above, the atoms (or molecules) of that material absorb photonic energy and then begin to spontaneously emit. Subsequently under the right conditions, the process of stimulated emission will begin. Common materials for dental lasers can be broadly designated as one of three types: a container of gas, a solid-state crystal, or a semiconductor. The active medium is at the center or core of the laser, termed the optical cavity.

Gas Lasers

The most common gas dental laser is carbon dioxide, which contains a gas mixture of carbon dioxide, helium, and nitrogen. Helium is not directly involved in the lasing process, but nitrogen does interact with the excitation process and ultimately transfers that energy to the carbon dioxide molecules.

A second gaseous laser is the argon ion instrument. A tube of this noble gas when excited can produce several radiant emissions, the most common being a visible blue and blue-green beam of collimated light. The physical demands of power and cooling have rendered this laser to a very limited application in dentistry.

One of the first lasers developed was the helium-neon gas laser, which has a visible red color emission.

Solid-State Crystal Lasers

Various solid-state crystals are used in dental lasers. The host material is composed of yttrium aluminum garnet (YAG), yttrium aluminum perovskite (YAP), or yttrium scandium gallium garnet (YSGG.) Any of these can then be «doped» with ions of neodymium, erbium, and chromium. The resulting designation would be written as Nd:YAG, for example, which would be a neodymium-doped yttrium aluminum garnet crystal.

Semiconductor Dental Lasers

A semiconductor laser utilizes the basic positive-negative (p-n) junction of everyday electronic circuits—the diode: that is, a two pole oppositely charged wafer. The flow of negatively charged electrons into the positively charged holes diffuses across the junction. The lasing action takes place between the charged layers, called the depletion region. This small rectangle will emit coherent and monochromatic light, but collimation must be performed by an external lens. Current diode lasers consist of various atomic elements in binary, ternary, or quaternary form arranged in a wafer-like structure. Examples would be gallium arsenide (GaAs), aluminum gallium arsenide (AlGaAs), indium gallium arsenide (AlGaAs), and indium gallium arsenide phosphate (InGaAsP.) These elements provide a checkerboard-like crystalline structure to allow lasing to occur; the usual silicon-based semiconductor is not used because of its symmetry. The single diode wafer just described is then arranged in a linear array for cooling, and the number of wafers determines the power output.

2.5.2 Pumping Mechanism

Surrounding this optical cavity with its active medium is an excitation source, known as the pumping mechanism. Pumping is used to transfer energy into the optical cavity, and that energy must be of sufficient quantity and duration so that the occupation of a higher energy level exceeds that of a lower level. This condition is called a population inversion and it allows amplification to occur.

Although the above-described process occurs rapidly, it still takes some time. Most lasers are described as three-level or four-level. A three-level system describes the basic concept: level one would be the stable, ground state, sometimes designated as energy level zero, a pumped level (energy level 2), and a lasing level (energy level.) Despite rapid decay from level 2, with enough pumped energy, there will be a population inversion between level 1 and 2. A four-level system is similar with the pumped level designated as 3, the upper lasing level as 2, and the lower lasing level as 1. The difference between these two lasing levels will aid in producing a population inversion. Certain active media operate as either three- or four-level systems.

In the laser industry, there are a wide variety of pumping mechanisms. The pumping of dental lasers is usually performed with optical devices—high-power lamps or lasers or by electricity—either with direct current mains or with electronic modulation of alternating current. Currently diode lasers are electronically pumped; solid-state crystal lasers use high-powered strobes (flash lamps); and carbon dioxide lasers can be operated with AC or DC current or radiofrequency (RF) pumping methods. As a variation in pumping, one form of carbon dioxide technology uses very high pressure gas and many electrodes along the length of the gas tube. This is known as a transversely excited atmosphere (TEA) laser.

2.5.3 Resonator

The resonator, sometimes known as the optical cavity or optical resonator, is the laser component surrounding the active medium. In most lasers, there are two mirrors one at each end of the optical cavity, placed parallel to each other, or in the case of a semiconductor, either a cleaved and polished surface exists at the end of the wafer or there is reflection within the wafer. In all cases, these mirrored surfaces then produce constructive interference of the waves: that is, the incident wave and the reflected wave can superimpose on each other producing an increase in their combined amplitude. Clearly some waves will not combine and will soon lose their intensity, but others will continue to be amplified in this resonator. With the mirror system, this continued effect will help to collimate the developing beam. As mentioned previously, a diode laser collimation occurs externally.

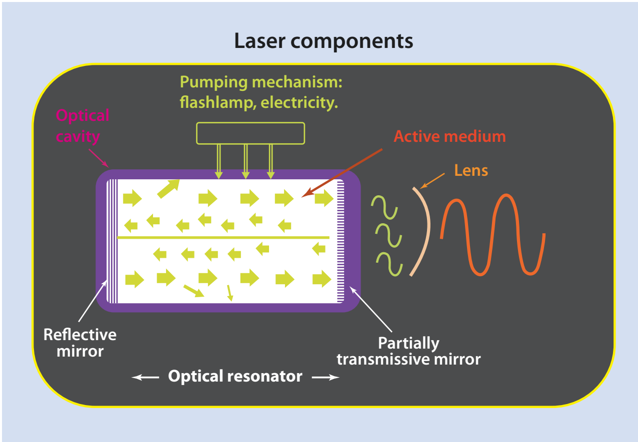


Fig. 2.3 General schematic of a laser. The active medium can be solid state (like Nd:YAG) or a gas (like carbon dioxide.) The pumping mechanism provides the initial energy, and the resonator consists of the active medium and axial mirrors. One mirror is totally reflective and the opposite one is partially transmissive. When a sufficient population inversion is present, laser photonic energy is produced and focused by lenses

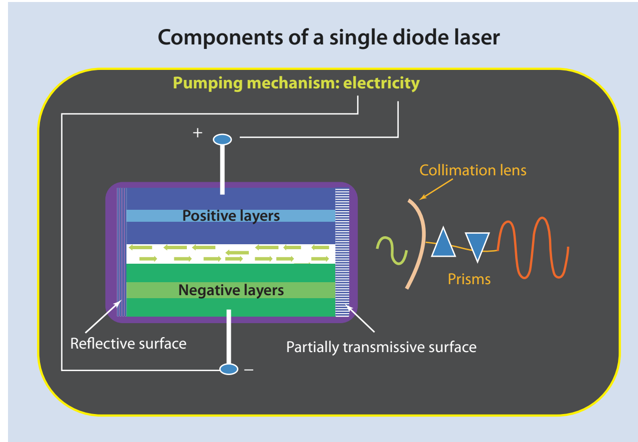


Fig. 2.4 Schematic of a single (individual) diode laser wafer. There are layers of positively and negatively charged compounds, pumped by electricity. The white layer with the yellow arrows represents the active layer where stimulated emission takes place. In this example, a reflective coating is applied to opposite ends of the wafer. In the right area are examples of lenses and prisms that would be placed at the emission end of an array of wafers to produce useful powers of diode laser photonic energy

2.5.4 Other Mechanical Components

A cooling system is necessary for all lasers, and higher output power requires increasing dissipation of the heat produced by pumping and stimulated emission. Air circulation around the active medium can control the heat, especially with diode lasers; the sold state crystal lasers and some gaseous lasers require additional circulating water cooling.

Focusing lenses are employed for each beam, and in the case of diode lasers, for collimation. The delivery system will ultimately determine the diameter of the emitted wavelength.

The laser control panel allows the user to adjust the parameters of energy emission, along with a foot or finger switch for «on-off» or variable output operation on some devices.

2.5.5 Components Assembled

Laser energy is produced because the active medium is energized by the pumping mechanism. That energy in the form of photons is absorbed into the active medium, raising its atomic electrons to higher orbital levels. As the electrons return to their stable ground state, photons are emitted while other entering photons can produce stimulated emission. The resonator allows more numbers of these photonic interactions and will continue the amplification process.

The operation is temperature controlled, the beam is focused, and the clinician can control the laser used. Figure 2.3 shows a graphic of a solid-state laser such as an Nd:YAG or a gas laser such as carbon dioxide, and Fig. 2.4 depicts a schematic of a single semiconductor laser wafer. Tables 2.1 and 2.2 provide details of the currently available dental lasers with their active medium, common usage, and emission wavelength.

Table 2.1 Currently available visible spectrum dental lasers

Type of laser and emission spectrum	General uses	Active medium	Wavelength	Emission mode
Semiconductor diode, visible blue	Soft tissue procedures, tooth whitening	Indium gallium nitride	445 nm	CW, GP
KTP solid-state visible light emission	Soft tissue procedures, tooth whitening	Neodymium-doped yttrium aluminum garnet (Nd:YAG) and potassium titanyl phosphate (KTP)	532 nm	CW, GP
Low-level lasers, visible red light emission semiconductor or gas lasers	Photobiomodulation therapy (PBM), photodynamic therapy (PDT), or carious lesion detection.	Variations of gallium arsenide or indium gallium arsenide phosphorus diodes Helium-neon gas	600–670 nm 632 nm	CW, GP

The type of laser and its emission spectrum is listed in column 1; column 2 indicates the general usage in dentistry; column 3 describes the active medium; column 4 shows the emission mode with the following abbreviations: *CW* continuous wave, *GP* acquired pulse

Table 2.2 Currently available invisible infrared dental lasers

Type of laser and emission spectrum	General uses	Active medium	Wavelength	Emission mode
Low-level lasers, (invisible) near infrared	Photobiomodulation therapy (PBM) , photodynamic therapy (PDT)	Variations of aluminum gallium arsenide diodes	800–900 nm	CW, GP
Semiconductor diode, near infrared	Soft tissue procedures	Aluminum gallium arsenide	800–830 nm	CW, GP
Semiconductor diode, near infrared	Soft tissue procedures	Aluminum/indium gallium arsenide	940 nm	CW, GP
Semiconductor diode, near infrared	Soft tissue procedures	Indium gallium arsenide	980 nm	CW, GP
Semiconductor diode, near infrared	Soft tissue procedures	Indium gallium arsenide phosphorus	1064 nm	CW, GP
Solid state, near infrared	Soft tissue procedures	Neodymium-doped yttrium aluminum garnet (Nd:YAG)	1064 nm	FRP
Solid state, near infrared	Soft tissue procedures, endoscopic procedures	Neodymium-doped yttrium aluminum perovskite (Nd:YAP)	1340 nm	FRP
Solid state, mid infrared	Soft tissue procedures, hard tissue procedures	Erbium, chromium-doped yttrium scandium gallium garnet (Er,Cr:YSGG)	2780 nm	FRP
Solid state, mid infrared	Soft tissue procedures, hard tissue procedures	Erbium-doped yttrium aluminum garnet (Er:YAG)	2940 nm	FRP
Gas, far infrared	Soft tissue procedures, hard tissue procedures	Carbon dioxide (CO_2) laser, with an active medium isotopic gas	9300 nm	FRP
Gas, far infrared	Soft tissue procedures	Carbon dioxide (CO_2) laser with an active medium of a mixture of gases	10,600 nm	CW, GP, FRP

The type of laser and its emission spectrum is listed in column 1; column 2 indicates the general usage in dentistry; column 3 describes the active medium; column 4 shows the emission mode with the following abbreviations: *CW* continuous wave, *GP* acquired pulse, *FRP* free-running pulse

2.6 History of Laser Development

After Einstein's laser theory was published, experiments to build a device didn't appear until the 1950s. Charles Townes of Columbia University in New York began working with a microwave amplification in 1951. In 1957 another Columbia graduate student Gordon Gould described in his laboratory notebook the basic idea of how to build a laser. That was considered the first time the term was used. The first laser was built by Dr. Theodore Maiman in 1960 at Hughes laboratory [16]. He used a 1 × 2 cm synthetic ruby cylinder for the active medium and photographic flash lamps for the pumping mechanism and produced a brilliant red light pulsed emission. At the end of that year, three other scientists at Bell labs developed the helium-neon gas laser with a continuous output of red light. Other wavelength instruments were rapidly developed during that decade. Notable is the 1964 invention of the carbon dioxide laser, with a 10.6 micron wavelength, by Kumar Patel, and, in the same year, the Nd:YAG laser was built by Joseph Geusic and Richard Smith, all at Bell labs. In the spring of 1970, a team of Russian and American scientists independently developed a continuous wave room temperature semiconductor laser [17]. The first laser specifically designed for dentistry was marketed in 1989 [18].

2.7 Laser Delivery Systems

Laser energy can be delivered to the surgical site by various means that should be ergonomic and precise. There are three general modalities:

- **An optical fiber**
- **A hollow waveguide**
- **An articulated arm**

Fig. 2.5 An optical fiber assembly

Fig. 2.6 A hollow waveguide assembly

2.7.1 Optical Fiber

An optical glass fiber usually made of quartz-silica. This glass core conducts the laser beam along its length. A thin polyamide coating surrounds the core to contain the light, and a pliable thicker jacket covers both to protect the integrity of the system. A specific connector couples the fiber to the laser instrument; a handpiece and tip are added to the operative end. Figure 2.5 shows a typical optical fiber assembly.

2.7.2 Hollow Waveguide

A hollow waveguide is a jacketed flexible tube. The internal surface has a reflective coating like silver iodide to allow the beam's transmission. A series of protective jackets complete the system. The waveguide is connected to the emission port on the laser, and a handpiece and optional tip are connected to the operative end. Figure 2.6 shows a typical hollow waveguide assembly.

2.7.3 Articulated Arm

An articulated arm consists of a series of reflective hollow tubes with pivoting internally mirrored joints along its length. The arm has a counterweight to provide ease in movement. The laser emission port is coupled with the first tube, and a handpiece and optional tip are added to the operative end of the distal tube. Figure 2.7 shows the basic arm assembly.

Shorter wavelength instruments, such as KTP, diode, and Nd:YAG lasers, have small, flexible fiber-optic systems with bare glass fibers or disposable tips that deliver the laser energy to the target tissue. A few low-powered diode lasers are offered as handheld units with disposable glass tips.

Fig. 2.7 An articulated arm delivery system

Erbium devices are constructed with more rigid glass fibers, semiflexible hollow waveguides, or articulated arms. Carbon dioxide lasers use waveguides or articulated arms. Some of the erbium systems employ small quartz or sapphire tips, and carbon dioxide instruments employ metal cylinders that attach to the handpiece. All of the tips are used for contact with target tissue, although they can direct the beam toward the tissue when not directly touching it. Other lasers in these wavelengths use tip less (and therefore noncontact) delivery systems. In addition, some procedures demand that a clinician not directly contact the tissue. In addition, the erbium lasers and the 9.3 micron carbon dioxide laser employ a water spray for cooling hard tissue.

2.7.4 Contact and Noncontact Procedures

All conventional dental instrumentation, either hand or rotary, must physically touch the tissue being treated, giving the operator instant feedback. As mentioned, dental lasers can be used either in contact or out of contact. Clinically, a laser used in contact can provide easy access to otherwise difficult-to-reach areas of tissue. The fiber tip can easily be inserted into a periodontal pocket to remove small amounts of granulation tissue, for example. In noncontact, the beam is aimed at the target at some distance away from it. This modality is useful for following various tissue contours, but the loss of tactile sensation demands that the surgeon pays close attention to the tissue interaction with the laser energy.

The active beam is focused by lenses. With the hollow waveguide or articulated arm, there will be a precise spot at the focal point where the energy is the greatest, and that spot should be used for incisional and excisional surgery. For the optic fiber, the focal point is at or near the tip of the fiber, which again has the greatest energy. When the handpiece is moved away from the tissue and away from the focal point, the beam is defocused and becomes more divergent. At a small divergent distance, the beam can cover a wider area, which would be useful in achieving hemostasis. At a greater distance away, the beam will lose its effectiveness because the energy will dissipate. This concept will be further discussed in ► Sect. 2.8.

2.7.5 Aiming Beam

All the invisible dental lasers are equipped with a separate aiming beam, which can either be laser or conventional light. The aiming beam is delivered coaxially along the fiber or waveguide and shows the operator the exact spot where the laser energy will be focused.

2.8 Emission Modes

There are two natural modes of wavelength emission for dental lasers, based on the excitation source: continuous wave and free-running pulse. A subset of continuous wave mode is a gated pulsed emission, where there is some means of modification performed after the beam is initially generated.

2.8.1 Continuous Wave

Continuous wave emission means that laser energy is emitted continuously when the laser is switched on and produces constant tissue interaction. These lasers are pumped with a constant direct current electrical field source. KTP, diode, and older model CO_2 lasers operate in this manner. The energy and/or power have a level output.

2.8.2 Free-Running Pulse

Free-running pulse emission occurs with very short bursts of laser energy due to a very rapid on-off pumping mechanism. Two examples are a high-powered strobing lamp or a radiofrequency electronic field. The usual pulse durations of energy can be measured in microseconds, and there is a relatively long interval between pulses. The power produced has a high peak and low average level, which will be discussed in ► Sect. 2.9. Nd:YAG, Nd:YAP, Er:YAG, and Er,Cr:YSGG and some carbon dioxide devices operate as free-running, direct pulsed lasers.

2.8.3 Gated Pulsed Mode

Some laser instruments are equipped with a mechanical shutter with a time circuit or a digital mechanism to produce pulsed energy. Pulse durations can range from tenths of a second to several hundred microseconds. Some diode and carbon dioxide lasers have these gated pulses from their continuous wave emission. There can be high peak and low average power levels produced.

Another method to produce very short pulses is called Q switching (the Q indicates the quality factor of the optical resonator.) An attenuating mechanism modulates the rate of stimulated emission, while the pumping mechanism continues to provide energy into the resonator. When the Q switch is turned off (opened), the result is a very short pulse of light, on the order of tens of nanoseconds. Peak powers can be very high.

Alternatively, an acousto-optic modulator can be placed in the laser cavity to ensure that the phases of emission all constructively interfere with each other. This is called mode-locking and can produce pico- or femtosecond pulse durations with resulting extremely high peak powers.

Current dental lasers do not utilize Q switching or mode-locking emission modes.

2.9 Terminology

The laser instrument's wavelength has a unique and unchangeable photon energy emission. However, the clinician can adjust various parameters of that emission from both the control panel and the handpiece's position on the target tissue. Throughout the remainder of this book, various terms will be used to describe the laser procedures. The Glossary at the end of this chapter contains many of the terms and definitions that are standard for lasers.

Table 2.3 Important terminology for laser use

Term	Definition	Abbreviation
Energy	The ability to do work	J (joule) or mJ (millijoule)
Fluence	Energy per area	J/cm^2
Power	Work performed over time	W (watt)
Power density	Power per area	W/cm^2
Beam size	The area of the projected laser beam on the tissue	(Usually measured in microns or millimeters)

Table 2.3 describes the fundamental terms that are common notations found in clinical procedures. A few of those terms will be described in more detail in this section.

2.9.1 Energy and Fluence

Energy is a fundamental physics term defined as the ability to do work. This energy is usually delivered in a pulse. A joule (J) is a unit of energy; a useful quantity for dentistry is a millijoule (mJ), which is one-one thousandth of a joule. Pulse energy is therefore the amount of energy in one pulse.

Fluence is a measurement of energy per area and is expressed as J/cm^2. This is also known as energy density. Procedures on different dental tissues will require various fluences for both efficiency and safety.

2.9.2 Power and Power Density

Power is the measurement of work completed over a period of time and is measured in watts (W.) One watt equals 1 joule delivered for 1 s.

Power density is the measurement of power used per unit of area and is expressed as W/cm^2. Alternate terms are intensity or radiance.

2.9.3 Pulses

Except for continuous wave operation, all lasers can produce pulsed emission; that is, several bursts of energy can occur in a second. The number of pulses per second (pps) is the usual term applied, and an alternate word is hertz. That word could be confused with the description of the number of cycles per second of alternating electrical current.

Pulse Duration, Pulse Interval, and Emission Cycle

The length of each pulse is called the pulse duration or sometimes pulse width and can be as short as one microsecond (10^{-6} s.) The pulse interval is that time period between the pulses, when no laser energy is emitted. The emission cycle is the ratio, usually expressed as a percentage of the individual pulse duration to the total time of that pulse duration plus the subsequent pulse interval. In other words, if the pulse duration is 0.5 s and the pulse interval is 0.5 s, that is one pulse per second and the emission cycle is 50%. The emission cycle is sometimes referred to as the duty cycle. Similar to hertz, that similarity is unfortunate since the phrase duty cycle actually refers to how long on a device can remain on and working before it must be switched off for cooling.

2.9.4 Average and Peak Power

Average power is what the tissue experiences during the duration of the procedure. Peak power is the power of each pulse. Obviously, with continuous wave lasers, there is really no peak power. For any pulsed laser, the average power will be less than the peak power.

The calculation of peak power is the result of dividing the pulse energy by the pulse duration. For example, a 100 mJ pulse with a duration of 100 µs would have a peak power of 1000 W. This a common peak power achieved in free-running pulsed dental lasers. However, those same lasers are generally used with a low pulses per second parameter, which means that the pulse interval is relatively large. This results in a correspondingly low percentage emission cycle. Using the above example of a pulse duration of 100 µs at 50 pulses per second, the total emission time is 5/1000 of a second, which means the total pulse interval is 995/1000 of a second. The duty cycle is then calculated at approximately 1%. Figure 2.8 shows a graphic depicting the relationship between peak and average power with basic laser parameters.

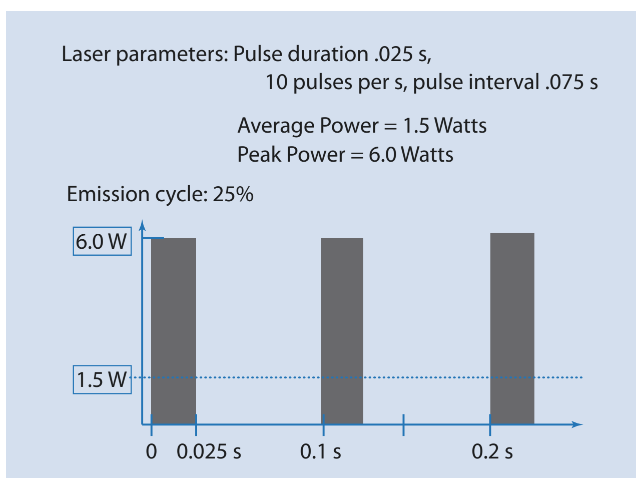


Fig. 2.8 This graphic shows the relationship between peak and average power along with the emission cycle. The pulses of laser energy are depicted in *dark gray* bars. The individual pulse duration is 0.025 s and the pulse interval is 0.075 s. Each pulse has a peak power of 6 watts, but the average power is 1.5 watts, due to the emission cycle of 25%

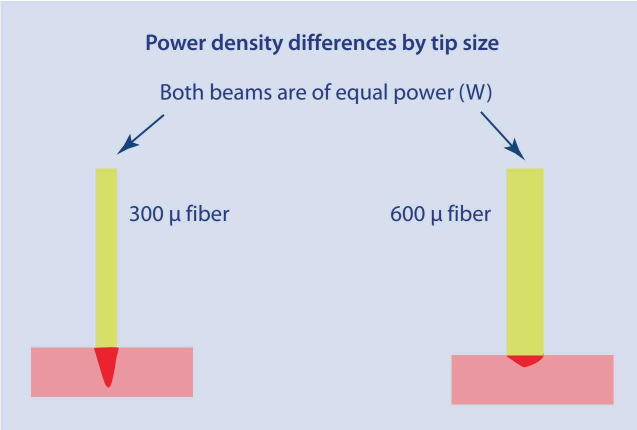


Fig. 2.9 This graphic shows the difference between power density areas using a 300 micron tip/beam size and a 600 micron tip/beam size. The smaller fiber has a larger area of interaction because of the larger power density calculation

Fig. 2.10 An 810 nm diode laser with a 400 micron contact fiber was used at 1.0 W continuous wave for both incisions on a porcine maxilla specimen. The left incision was made with a faster vertical movement than the right incision. The left incision is narrower; the right incision is wider and more ragged and produced a higher temperature in the tissue. Thus, the power density was larger for that incision

2.9.5 Beam Size

This is the area of the photonic emission that will interact with the target tissue. Lasers that employ tips have their nominal size indicated on the tip, and noncontact lasers also have an area of focus. Laser tips are available in several diameters; typical sizes are 200, 300, 400, and 600 microns. Other tip less lasers can produce beam sizes with similar measurements. Clearly, the fluence and power density measurements will be based on that beam size. As mentioned previously, the laser beam will diverge at a prescribed angle from a quartz or sapphire tip, increasing its area. Likewise a focused beam from a tip less delivery system will have a larger area when the beam is defocused. If the average power remains the same, both the fluence and the power density will be reduced.

Conversely, choosing a smaller diameter tip or producing a smaller focused area would increase the fluence or power density with the same laser output setting. This could affect the tissue interaction. Figure 2.9 is a graphic showing how the difference in tip sizes would affect the power density.

2.9.6 Hand Speed

In addition to the above parameter adjustments, an important principle of laser use is the speed at which the beam moves on the target tissue. A slower speed will increase the power density because of the longer time the energy remains in the tissue and could result in a larger area of interaction. This may or may not be a desirable effect, especially if the treatment objective is a minimally invasive procedure. Figure 2.10 shows a laboratory comparison of hand speed for soft tissue incision.

Summary
This chapter provided details of light and lasers. From basic experiments with light to the sophisticated development of different instruments, it should be clear that laser photonic energy can be precisely produced and controlled to be used for dental procedures.

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2

Laser–Tissue Interaction

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3

Core Message

The potential for laser–tissue interaction forms the basis of the usefulness of predictable employment of laser photonic energy as an adjunct to clinical dental and oral therapy. Appreciation of the underlying mechanisms together with acknowledgement of limitations will help the clinician to provide laser therapy and minimize collateral damage.

There is an often-cited belief that in order to obtain benefit from laser photonic energy irradiation of target tissue, there must be absorption of the energy. Such understanding has merit but not entire truth. Owing to the multistructural nature of oral hard and soft tissue, the possibility of incident photonic energy reacting in a definite, predictable and exclusive manner with target tissue molecules is flawed through the very nature of the varying structures. Interaction may be a combination of surface, deeper, scattered and refracted energy distribution, and true absorption of power values predicated through laser control panel selection may be impossible to achieve because of the varying interactive phenomena that may occur.

All oral tissues are receptive to laser treatment, but the biophysics governing laser–tissue interaction demands a knowledge of all factors involved in the delivery of this modality. Through this knowledge, correct and appropriate treatment can be delivered in a predictable manner.

This chapter looks at the concepts of electromagnetic energy distribution within oral hard and soft tissue and examines the potential for true photonic energy ablation of target molecules. Prime concepts of photothermal action as a pathway to tissue change are explained, and adjunctive spatial and temporal components of the incident beam and the effects of such variance are explored.

The inconsistencies of laser–tissue interaction continue to pose some difficulty for the dental clinician; however, the development of many laser machines, amounting to a facility to produce laser photonic energy at several wavelengths between the visible and far-infrared areas of the electromagnetic spectrum, addresses many of the inconsistencies.

3.1 Introduction

Our understanding of the concepts of color helps to define the interaction of an incident beam of multiwavelength (λ) electromagnetic (EM) energy – the so-called white light – with a target structure. Human interpretation of «light» as a concept is limited to the ability of the retina to respond to this energy and the visual cortex to correlate stimulation in terms of a very limited range of the EM spectrum (λ 350–750 nm), termed the «visible spectrum.» White light is seen in nature as the consequence of solar energy that filters through the many layers of the earth's atmosphere or the emission of a man-made incandescent light source. «Light waves» that arise from such sources are multidirectional (not in phase – incoherent) and of multiple energy values.

The fundamental theories on light of the latter nineteenth and early twentieth centuries – notably work of Maxwell, Planck, Hertz, Einstein and Bohr – provided a coalescence of the prevailing opinions of light being composed of either particles or waves. Newton, through his «Corpuscular» theorem [1], in which light traveled as discrete packets («corpuscles»), was at variance with earlier work of Huygens. Popular acceptance of a predominant belief in light propagation by waves reemerged in the early eighteenth century England with the slit experiments of Thomas Young [2]. The confirmation that light energy was a form of electromagnetic (EM) radiation, capable of causing a photoelectric effect with certain metals, proposed a duality of existence for «packets» of light energy. Einstein is attributed [3] with providing the annotation «photon» (one quantum – smallest unit – of electromagnetic energy is called a photon (origin Greek «φως», meaning «light»)) and, with others listed before, provided an understanding that photonic energy is a form of energized EM radiation, with each photon traveling at the speed of light (approx. 300×10^6 m/s) in a sinusoidal wave pattern. From this it is fundamental to our understanding of the so-called laser–tissue interaction that EM energy in its many forms is interrelated and the energy contained therein is capable of conversion to thermal and sonic equivalent within target tissue, through the law of conservation of energy (sic energy cannot be created or destroyed, just transformed from one form to another).

In determining a prescribed level of energy-derived physical change in target oral tissue, it is necessary to appreciate the quantity of incident energy, the degree of positive interaction and the potential for energy conversion. Inherent in every incident laser beam is the photonic energy.

Laser «light» is considered unique in that, unlike other forms of light (sunlight, incandescent, LED irradiation), there are two inherent properties – monochromaticity and coherence. The single wavelength concept is founded in the physics of laser EM propagation, and using the Einstein/Bohr postulations, the delivery of laser irradiation is in sinusoidal waveform with successive waves in phase – the so-called wave coherence. Additional man-made configuration of the photonic energy produced can provide high-density beam spatial density over distance – this is termed «collimation.» In terms of the benefits of laser–tissue interaction due to these properties, the monochromatic absorption of a chosen laser, together with the coherence of the beam, will offer selective tissue interaction of high quality; the collimation and ability to focus the beam will define a degree of accuracy and power density (PD).

Figure 3.1 provides examples of predictable laser–tissue interaction.

3.2 Photonic Energy

The emission of a single photon from an atom is the result of a shift in the energy status of that origin. Plank proposed all matter existed in a state of energy relative to extremes of a lower (ground) state and a higher (energized) state, commensurate with entropic physical form [4]. Boltzmann, through his theories on thermodynamics [5], readily

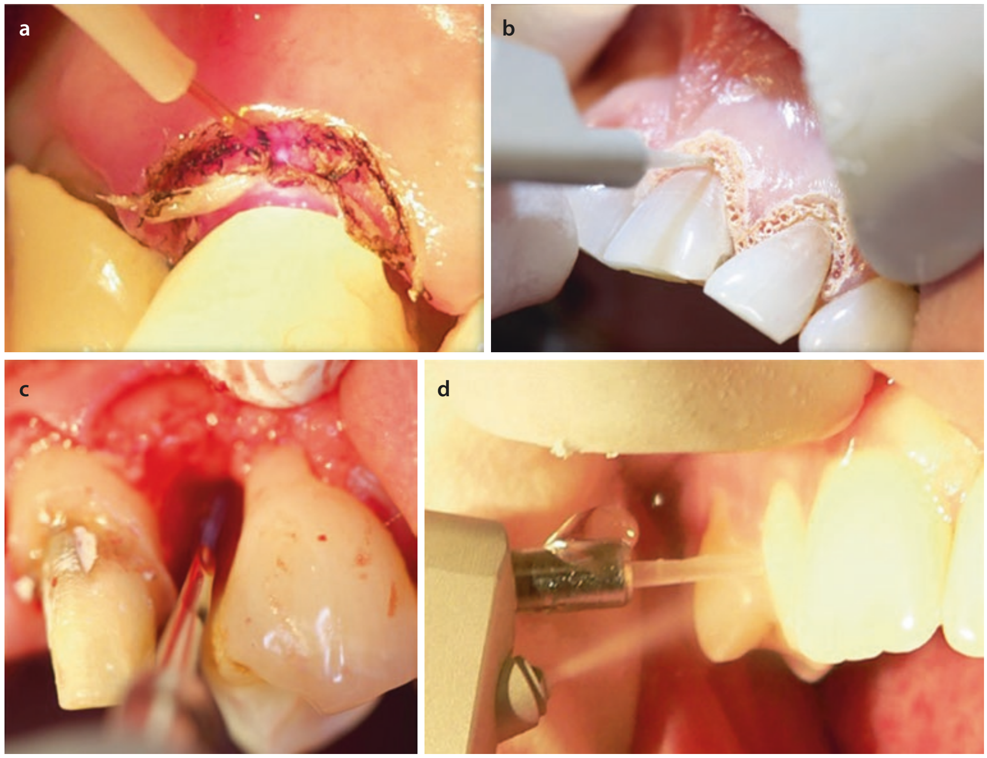

Fig. 3.1 Laser-assisted oral tissue surgery is photothermal in nature. Incident (photonic) energy is absorbed by target tissue elements (chromophores), relative to the laser wavelength. This leads to rapid temperature rise, protein denaturation, and water vaporization. This constitutes an example of photoablation

accounted a direct relationship between matter, energy and temperature. Put simply, an electric light filament at room temperature is a dull, inert wire but rapidly heats when energized by an electric circuit. The resistance of the wire leads to thermal conversion of the electrical (EM) energy. At this induced higher energy state of the light filament, the volatility of constituent electrons gives rise to higher thermal energy and the emission of such energy as light.

Laser photonic energy assumes the production of high-energy photons from an energized source, whereby each photon scribes an identical waveform and each photon has identical energy value. Plank and Einstein had established an inverse relation between wavelength and photonic energy, a direct proportional relationship between photonic energy and frequency, and Niels Bohr paved a way for the «quantum» (amount) nature of emitted photons to be calculated; thus, it provided a predictable base for the development of the MASER and optical-MASER or LASER.

The energy of emitted photons is expressed in Joules or, more conveniently, eV (energy derived by acceleration through a PD of 1 volt). Since photonic energy is related to wavelength (λ), photons emitted from different sources will have differing energy values. Basic calculation can be derived through:

$\lambda = hc/E$,

where h = Plank's constant, c = speed of light and E = photon energy in eV.

1 eV = 1.602×10^{-19} J and it is possible to evaluate energy-equivalent values for the many laser wavelengths; for example, photons of wavelength 1240 nm (near infrared) equate to an eV value of 1.0, whereas an eV value of 2.0 is 621 nm (visible red) and eV 0.13 equates to 9600 nm.

Table 3.1 Commonly used laser wavelengths associated with dental treatment

(eV)	Laser	λ (nm)
2.4	KTP	532
2.0	He-Ne	633
1.6	Diode	810
1.2	Nd:YAG	1064
0.4	Er:YAG	2940
0.1	CO_2	10,600

Photonic energy and wavelength are inversely proportional. With ascending numerical value of wavelength, the corresponding photonic energy (expressed in electron volt – eV) is reduced With ascending numerical value of wavelength, the corresponding photonic energy (expressed in electron volt – eV) is reduced

Table 3.1 provides an overview of laser wavelengths commonly used in dentistry with corresponding photonic values:

3.3 Photonic Energy and Target Molecular Structures

A simplistic look at one of the many graphic representations of the relationship of target tissue elements, incident laser wavelengths and relative absorption potential, would suggest