Overview of laser history and introduction to current dental applications

R. Riversa, M. Garrone, E. Trevisiol, V. Partipilo, M. Maggioni, E. Ruga

Light creates and nourishes life. The concept has been well known since ancient times. Primitive humans, through the discovery of fire, have guaranteed themselves survival and subsequent development through the cooking of food, the possibility of warming up and keeping away dangerous predators.

The ancient Egyptians embodied the sun in one of their most important deities: the god Ra and, like other ancient peoples, began to understand the effects of light on crops, as the seasons changed, and some therapeutic effects on humans.

Healing benefits were further developed by Greek and Roman civilization, until the Middle Ages with the first knowledge on heliotherapy and phototherapy.

Many philosophical studies are based on the contrast between light and darkness, between good and evil.[1]

The first theoretical and physical principles on electromagnetic radiation were formulated in 1901 and 1913 with Plank, through the study of quantum mechanics, and with Bohr, with the description of the atomic structure, until arriving at Einstein in 1916 who, in his "Zur Quantum Theorie Der Stralung", was the first to theorize the stimulated emission of light. This is how quantum physics was born. Bloch was the first to theorize the inversions of atomic populations and the radiation that came out of them.[1–3]

In 1951, Towens and then Weber amplified microwaves by creating the MASER (Microwave Amplification by Stimulated Emission of Radiation) precursor to modern LASER (Light Amplification by Stimulated Emission of Radiation).

The creation of the first ever laser was due to Maimann who, in 1960, created a pulsed ruby laser that emitted at 694 nm.[4]

The study of lasers accelerated rapidly due to the strong interest aroused in the military and telecommu-

nications. In 1961 the second ever laser was produced at Neodymium, in 1962 the first Diode laser (gallium arsenide), in 1966 the first lasers with flash lamp pumping systems and in 1967 the first CO_2 laser.[5]

The diffusion in the industrial field is now exponential and today this technology has become an integral part of our daily life.

The first applications of the laser in the dental field were in the early 1960s with the use of ruby lasers, which however produced harmful thermal effects. At that time there was still no precise knowledge about the action targets and absorption curves of the various laser wavelengths.

There were studies of the CO_2 laser which, with its wavelength of 10,600 nm, was well adapted to dental surfaces in sealing procedures. In the 1980s, the hemostatic capacity of CO_2 in surgical procedures was first certified.[2,3,6,7]

In 1974, the first YAG lasers began to be used. In particular, Yamamoto's studies of Nd:YAG's ability to inhibit the formation of caries both in vitro and in vivo ensured the development of this wavelength, so much so that Nd:YAG became the most recognized laser in the dental field.[8]

In the 1970s, with Mester, the first experimental studies were launched on the effects of Low Level Laser Therapy on animals.[9]

While dental research focused on finding the most appropriate wavelength for use on hard tissues, medicine went a long way towards using soft tissue lasers: ophthalmology, with the use of ruby laser in retina treatments, up to the use of CO_2 and Nd:YAG in other surgical practices (especially in the vascular field).

The introduction of laser technology into oral soft tissue surgery started due to the collaboration between oral surgeons, maxillofacial surgeons and otolaryngologists. In 1987, the FDA first authorized the use of laser technology in oral surgery.

In the late 1980s there was an epochal revolution, with the development of Er:YAG lasers that, through their elective affinity with water, allowed a huge capacity for use in the dental and dermatological fields.[10] The 2000s were characterized by a wide development of semiconductor lasers, widely distributed on the market due to their compactness, handling and versatility of use.

In recent years there has been a continuous evolution of laser technology, especially in the software management of pulse duration and in the shape and length of the wave, as well as in the creation of pulse trains to ensure specific effects on biological tissues. In the near future, there will certainly be further technological development which will open the door to new and unexpected frontiers of use in the multidisciplinary field.

Introduction to dental laser applications

Laser technology is now commonly used in the medical field. Practically all branches married it and, in some of them, it became an instrument of first choice: just think of ophthalmology with refractive surgery and treatments in vascular surgery (📷 4.1).[11–12]

Even in dentistry the laser is becoming increasingly successful, thanks to its peculiarities ,mechanisms of action and interaction with biological tissues. Compared to common light, laser electromagnetic radiation is generated not by spontaneous emission but by stimulated emission. From this aspect comes the origin of the acronym LASER (Light Amplification by Stimulated Emission of Radiation).

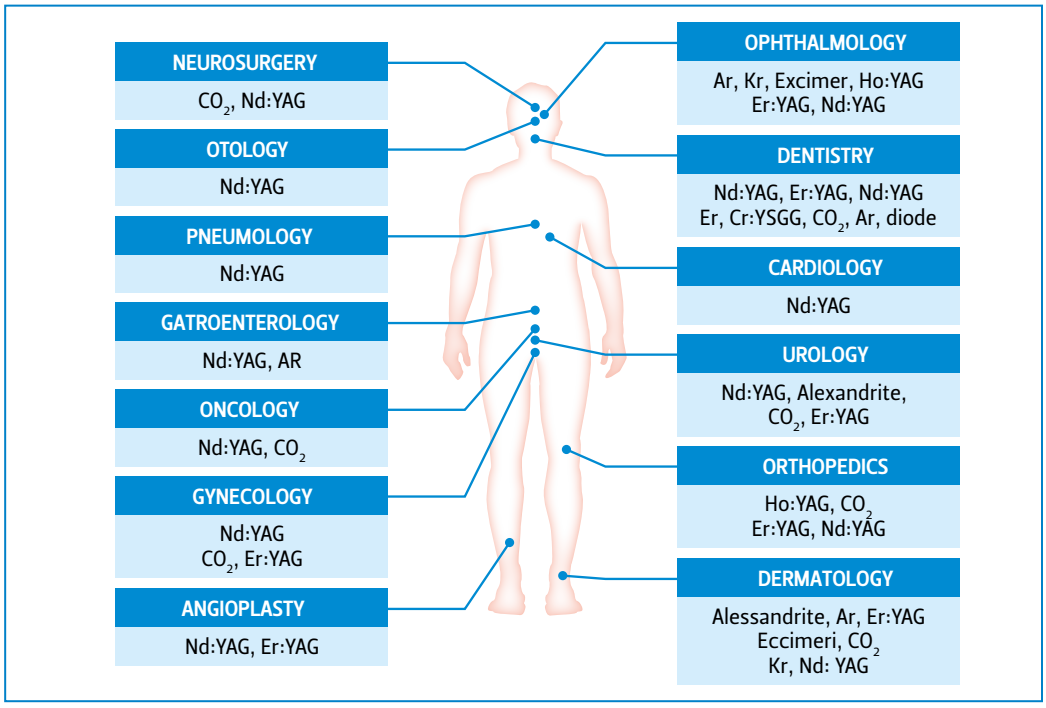
Stimulated generation means that laser light has three fundamental characteristics:

- *monochromaticity*: all electromagnetic waves produced have the same wavelength;
- *coherence:* all waves are identical in time and space;
- *collimation:* waves are transmitted in an orderly manner, parallel, without divergence.

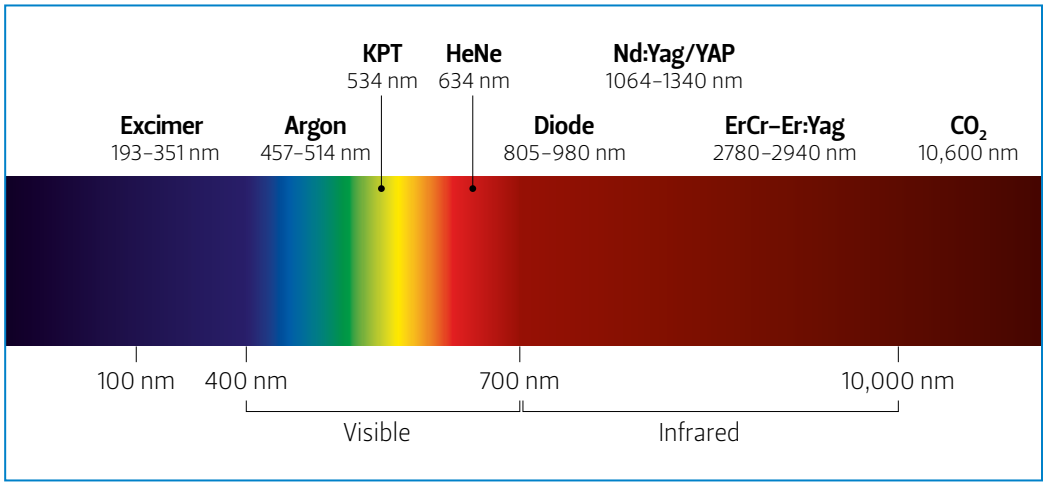
Similarly ordinary visible light, laser radiation has a wavy appearance, with main features such as wavelength and frequency, and corpuscular, carrying packets or energy quanta called photons.[12] Wavelength is the most important parameter of a laser. Medical lasers cover practically the entire spectrum of electromagnetic radiation, while in dentistry the most used ones are found in the visible and in the near and middle infrared area. (📷 4.2).

The study of absorption curves, especially absorption peaks, of the main laser wavelengths with respect to some organic components (biological chromophores), allows to understand the mechanism of action, selectivity and interaction with the different biological tissues and, consequently, the transformations that these can undergo (📷 4.3).[12,13]

In addition to the wavelength it is necessary to know other fundamental parameters of laser equipment (📁 4.1).



4.1 Common clinical applications of lasers in medicine.



4.2 The different types of lasers in the spectrum of electromagnetic radiation.

The progressive evolution, over the years, of the transition from continuous to increasingly pulsed emissions (reducing the duration of the single impulse to a few µs) is due to the need to act on our tissues as effectively as possible in the shortest possible time.

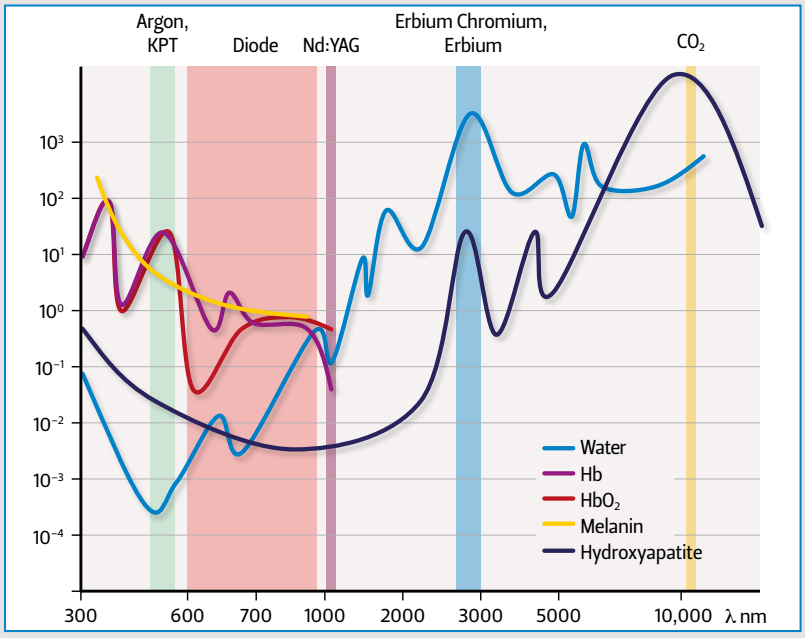
Reduced time intervals are preferred, which generate high peak powers and do not cause damage (mainly thermal) to the tissue itself and to the surrounding ones. This has a slower and more controllable action with the absence of carbonization (4.6).

As much as possible, by adjusting the duration of pulses and frequencies, an attempt is made to respect what is termed thermal relaxation time, the time that a tissue (due to its optical characteristics) takes to dissipate 50% of the absorbed heat (4.7 and 4.8).[14]

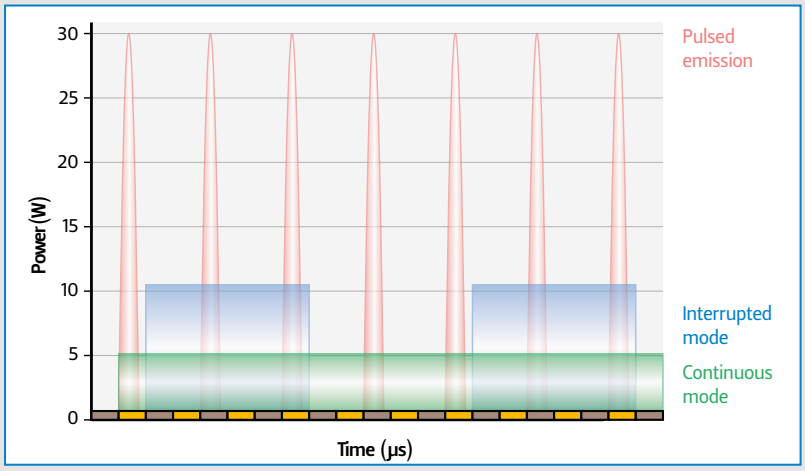
Next to the machine parameters we find the formulas that regulate the supply of laser energy respect to time and space (4.9).

Constituent components are common to almost all types of lasers on the market (4.10).

The only difference is in diode lasers, which do not have an optical resonator but a semiconductor that, acting as an active medium, crossed by electric current generates electromagnetic radiation.



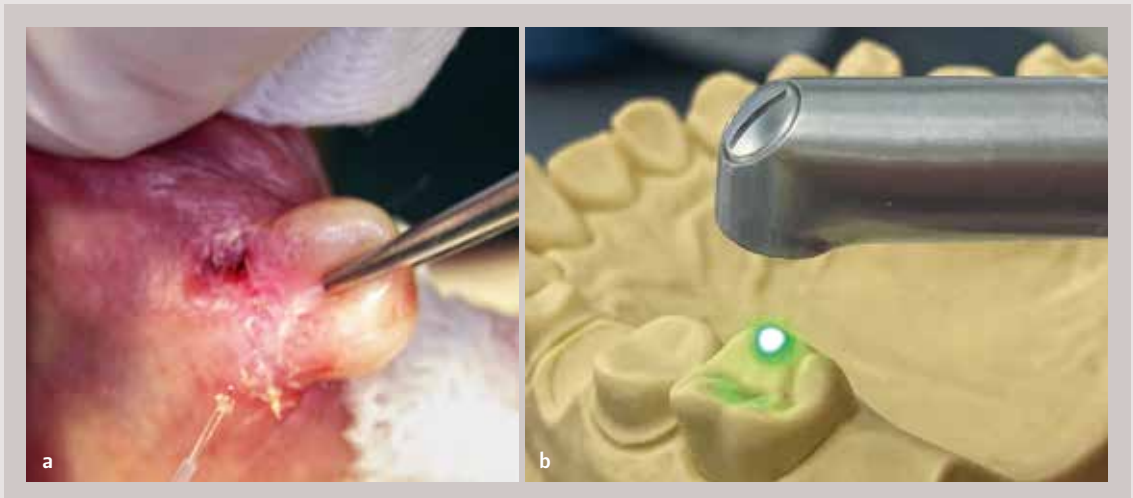
4.3 Absorption curves of the main laser wavelengths compared to the main biological chromophors.



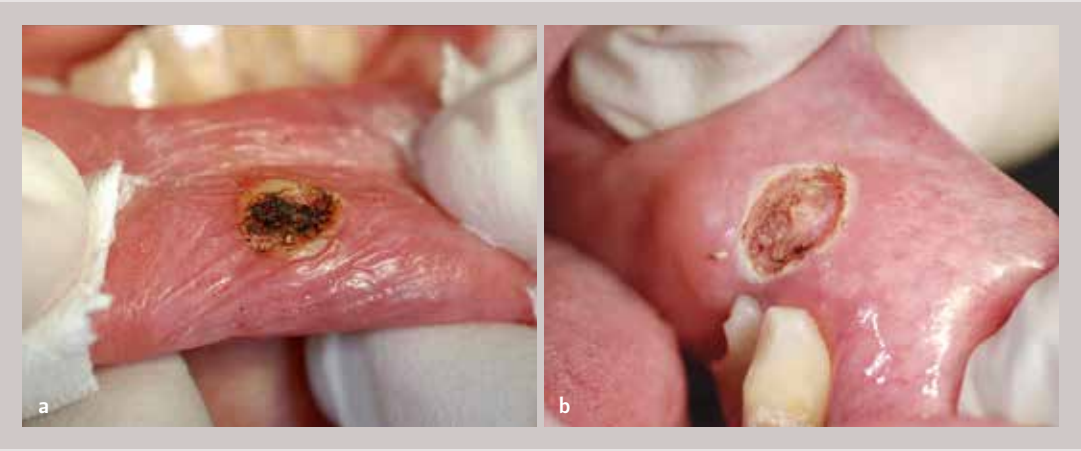
4.4 Mode of laser emission.

4.1 Key laser parameters

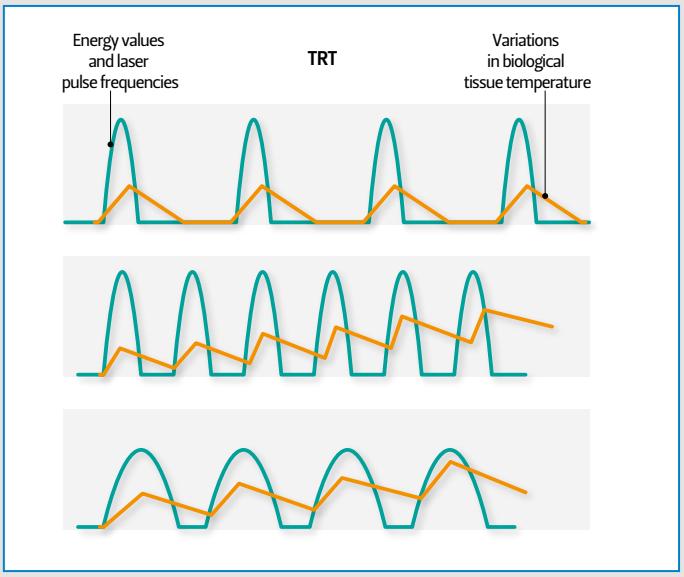
Wavelength	Laser type/Active element
Mode of emission	Continue, interrupted, pulsed, superpulsed (4.4)
Energy	milliJoule (mJ) - Joule (J)
Power	Watt
Frequency	Hz (Hertz) - pps (pulses per second)
Pulse duration	Milliseconds (ms) - microsecond (µs) - nanoseconds (ns) - picoseconds (ps) - femtoseconds (Fs)
Duty cycle	Laser efficiency ($t_{on}/t_{on} + t_{off}$)
Focus (spot and fiber diameter)	Contact use/not in contact use with the target tissue (4.5a and b)



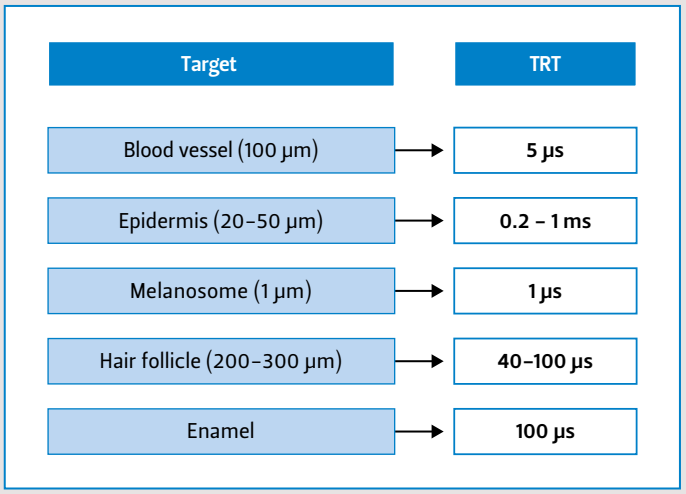
4.5 **(a)** Use of laser contact by fiber. **(b)** Non-contact laser use by collimated remote handpiece.



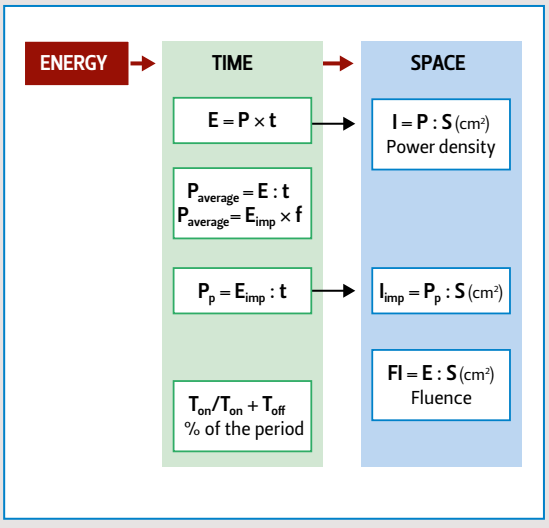
4.6 **(a)** Using a fiber 400 µm; mode of use: continuous; output power 1.5 W. The thermal damage reaches a depth of 125 µm. Dehydration and protein denaturing are obtained. Carbonization is connected to the depth of thermal damage. **(b)** Use of a 400 µm fiber; pulsed emission, frequency 20,000 Hz; pulse duration 10 µs; peak power: 25 W. Thermal damage between 15 and 25 µm. No visible carbonization. (Courtesy of ORALIA Laser.)



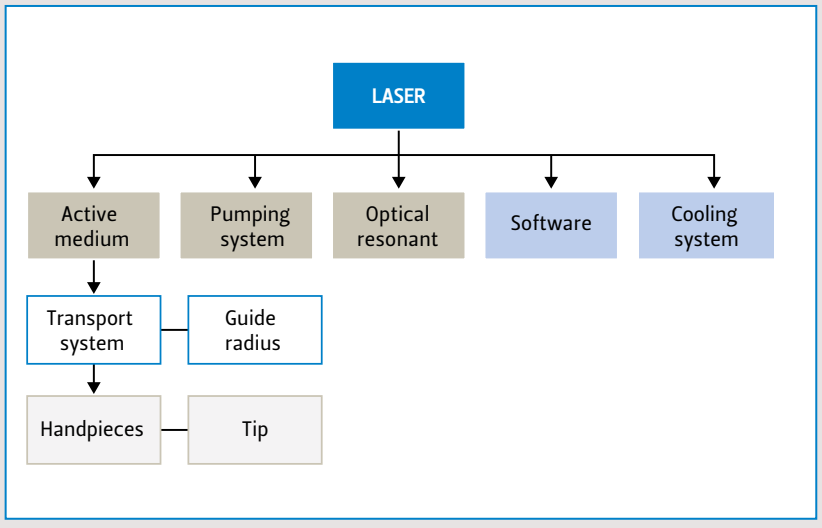
4.7 Variations in tissue thermal relaxation time with respect to energy values and laser pulse frequencies.



4.8 Variability of thermal relaxation times in different tissue targets.



4.9 Formulas that regulate the supply of laser energy.



4.10 Diagram of the main constituent components of a laser.

Light interacts with matter based on several mechanisms that modify its propagation (📷 4.11).[14,15–22]

The laser, due to its specific wavelength, has an elective affinity with precise targets (biological chromophores) and the absorption of energy by these targets determines the mechanisms of transformation of the tissues in which they are contained.

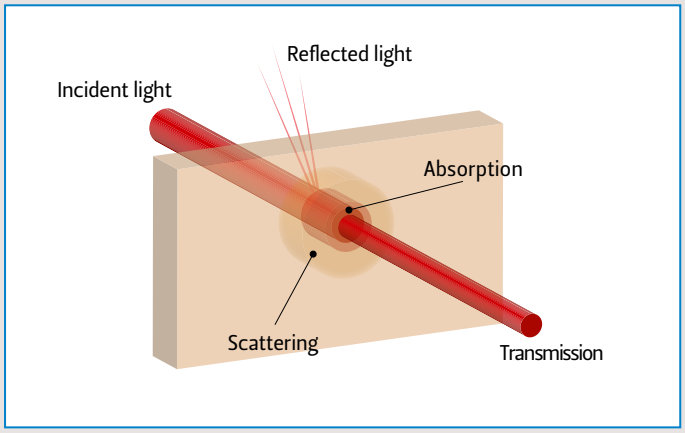
The transformations that can be had in biological tissues can be of different types (📷 4.12).[15]

The same distribution can be represented based on the fluency used for the different treatments (📷 4.13).

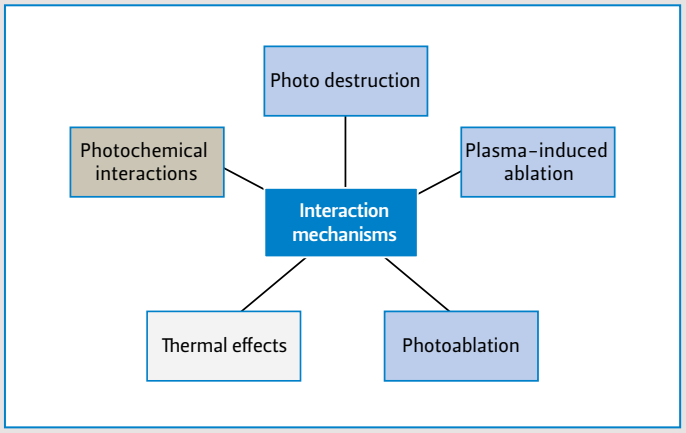
Among the interaction mechanisms of greatest interest in the dental field are photothermal and photochemical effects and, in part, photoablation effects for certain types of lasers.

Photothermal effects are nonspecific and depend on temperature increase (📷 4.14).

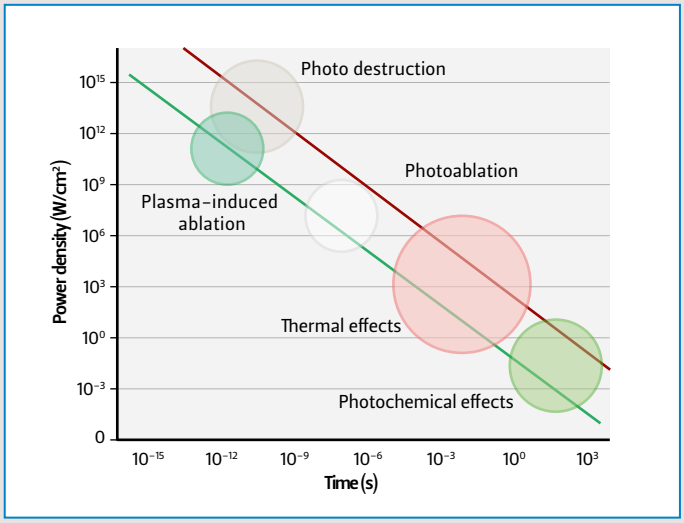
The energy of the laser absorbed by the target chromophore results in an increase in the kinetic energy of



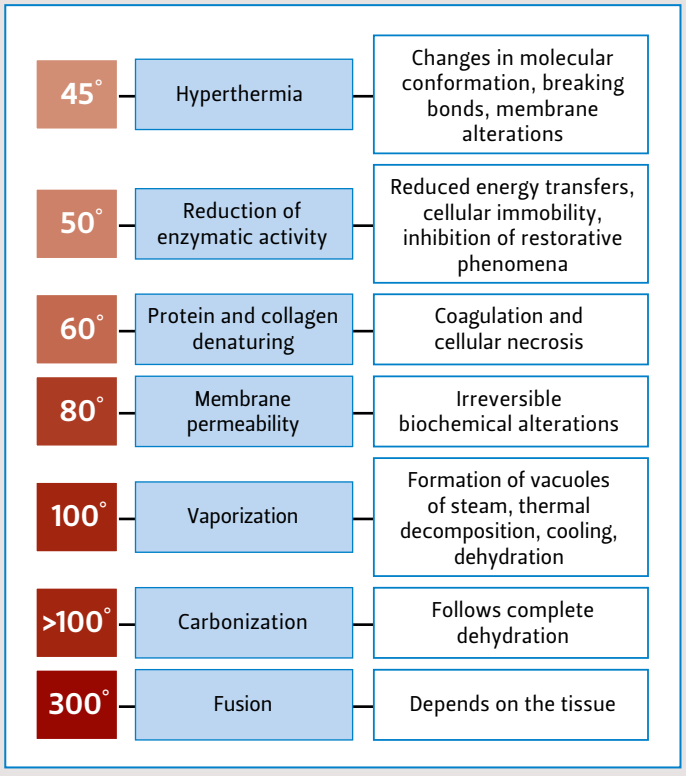
📷 **4.11** Interaction between lasers and tissues.



📷 **4.12** Laser-induced transformations in biological tissues.



📷 **4.13** Laser-induced effects on target tissues as fluence changes.



📷 **4.14** Photothermal effects of laser on target tissues.

the target's atomic components; the increase in kinetic energy in inelastic structures, such as most human biological tissues, leads to a progressive increase in temperature and corresponding effects.[14,16–22]

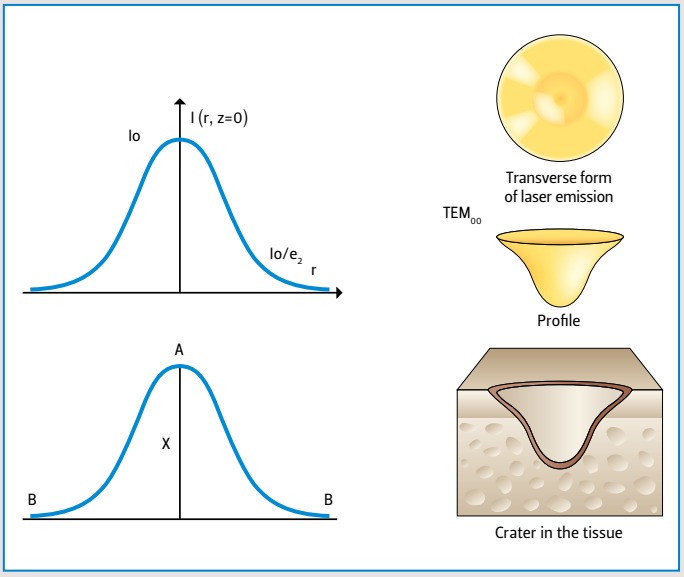
A particular effect that is witnessed is the divergence that the radius undergoes by interacting with the tissues. The angle of divergence, characteristic for each wavelength, produces an interaction that can be represented with a Gaussian curve.

In the tissue you will have the maximum radiation intensity at the central point but, at a distance X, it will be dispersed over a three-dimensional conical section. This dispersed portion ensures a photobiomodulation effect on the tissues being treated (4.15)[12–23]

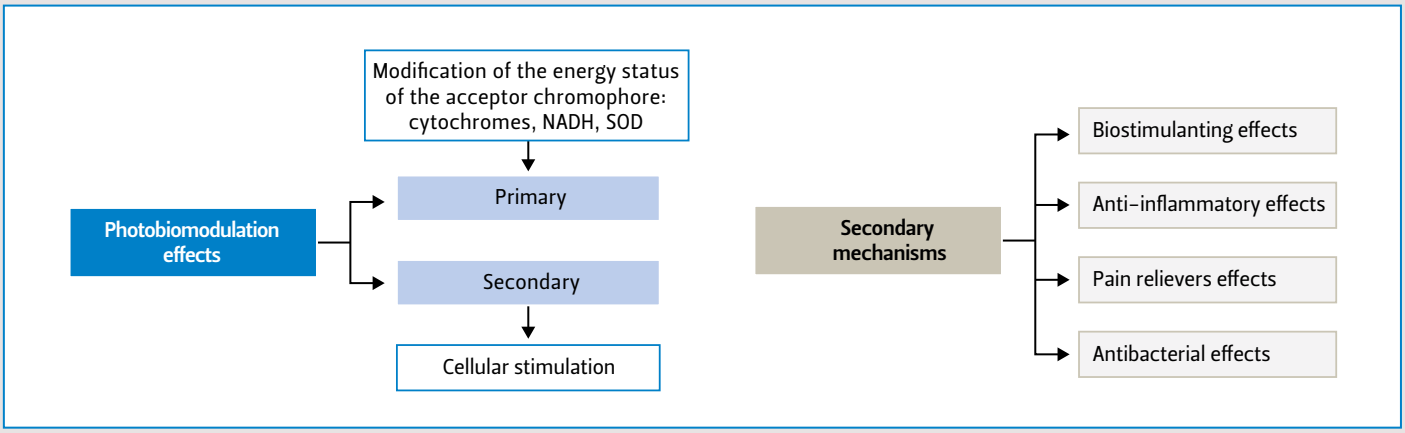
Photochemical interactions, which are the basis of photobiomodulation, are instead more specific and are based on the administration of precise amounts of energy on surface units expected to determine biochemical transformations in the target tissues through primary and secondary mechanisms (4.16).

The law that best sums up this principle is that of Arndt-Schulz.[13,23] (For further information, see Chapter 5.)

Laser, because of its properties and selectivity, is now used in all areas of dentistry (4.2).[11] Among the most commonly used lasers in dentistry are diode lasers, Er:YAG, Nd:YAG, CO_2, the main properties of which are summarized in Tables 4.3–4.6.



4.15 Graphic representation of laser irradiation intensity in interaction with tissues.



4.16 Primary and secondary mechanisms of photobiomodulation.

4.2 Dental applications of lasers

- Diagnosis
- Surgery and oral pathology
- Implantology
- Restorative dentistry
- Endodontics
- Orthodontia and pedodontia
- Photobiomodulation–LLLT
- Periodontology
- Esthetics of perioral tissues

4.3 Properties of diode laser

- Semiconductor lasers, wavelengths between 400 and 2000 nm
- The most widely used active substance is gallium and aluminum arsenide (GaAlAs)
- Very compact and handy lasers
- Generate power from a few milliwatts to hundreds of Watts, working continuously or alternately or with the latest electronic pulse systems
- The lowest wavelengths are used in diagnostics and biostimulation, intermediate wavelengths from 808 to 1064 nm in biostimulation and surgery, depending on the powers and frequencies used
- The length of 980 nm is versatile but not created for surgical applications
- The 445–450 nm has an absolute greater affinity for hemoglobin, with a marked hemostatic effect and thermal action. This is followed by lasers of 808–810 nm, 915 nm and secondly 940–980 nm
- Decontaminating action in both periodontology and endodontics by thermal action on bacterial structure
- Photobiomodulation effect with low fluencies on biological tissues
- Thermal action is used for the closure of dentinal tubules in the treatment of sensitivity and pulp protection in cavity
- 200, 300, 320, 400, 600m fibers or tips are used; there are dedicated handpieces for bleaching and biostimulation
- Possibility of esthetic and vascular treatments for thermal effect with dedicated handpieces (📷 4.17 and 4.18)[13,15–23]

4.4 Er:YAG 2940 nm Laser Properties (📷 4.19 and 4.20)

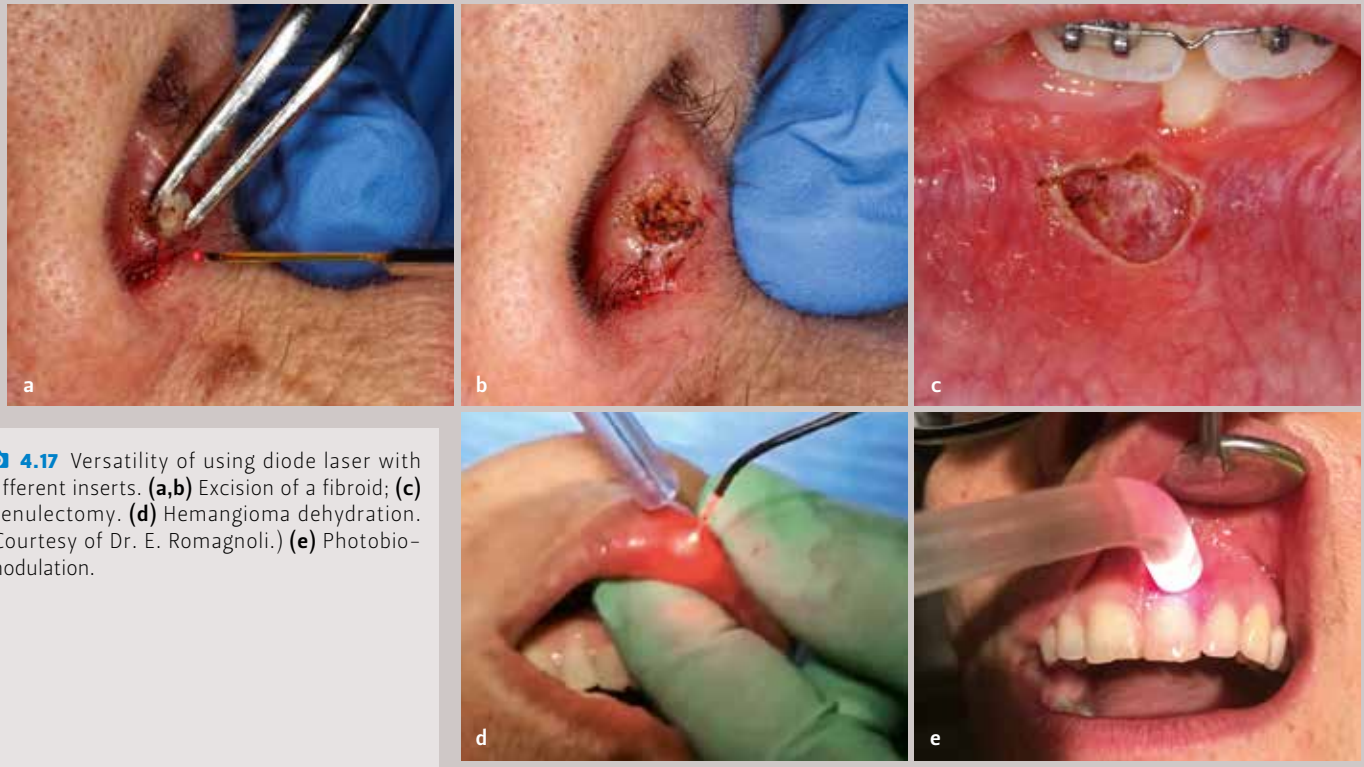
- Solid–medium laser (ittrium aluminum garnet doped with erbium), conveyed by hollow fibers or articulated arms, remote handpieces or with dedicated tips
- Work in a pulsed or super–pulsed way with very high peak powers, frequencies from 2 to 60 Hz and pulse length management
- Has a peak absorption for water
- Laser of choice in dentistry for the treatment of hard tissues (tooth, bone) by photo ablative effect
- Reduced thermal action, surface ablative effect
- It is used with water spray to facilitate cooling and promote the micro–explosion action of water molecules and, therefore, the photo ablative effect on tissues
- In soft tissue surgery it causes cuts by ablation with reduced hemostasis
- It is widely used through dedicated handpieces in esthetic treatments (photo rejuvenation and skin imperfections) of the face and neck and in the treatment of obstructive roncopathies[18–20]

4.5 Nd:YAG 1064 nm Laser Properties (📷 4.21 and 4.22)

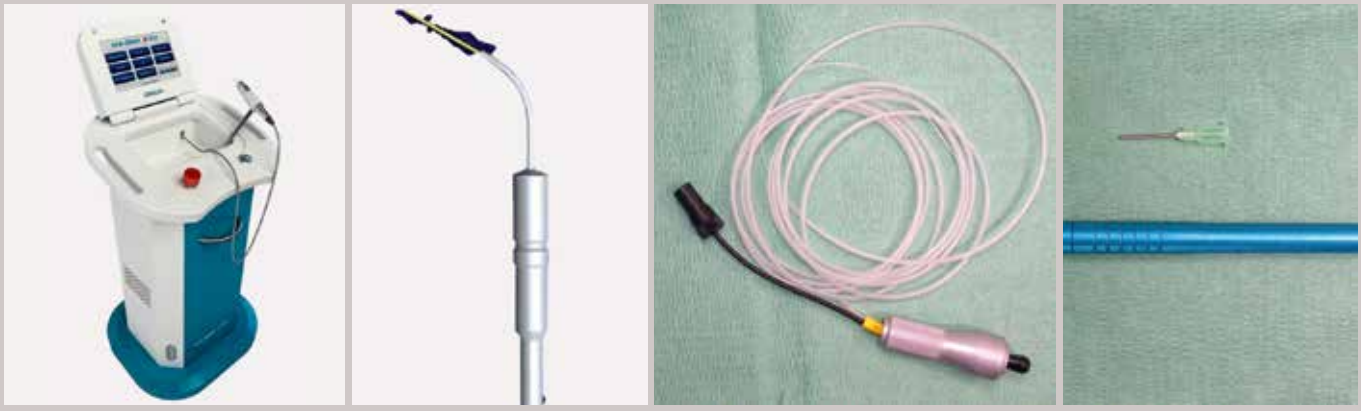
- Since 1987 used in dentistry
- The active medium is ittrium aluminum garnet doped with neodymium, wavelength of 1064 nm
- Works in both continuous and pulsed mode
- Fibers from 200 to 600 mm
- In dentistry continuous mode is not used due to the high thermal effect and considerable depth of penetration
- Used instead in pulsed mode determines very high peak power, respect for thermal relaxation time, lower penetration
- Great affinity with pigmented tissues and hemoglobin, surgical action, good hemostasis, decontaminating action in periodontology and endodontics
- Used in dentinal desensitization due to thermal effect of tubule obliteration
- Used with dedicated handpieces in oral and peri–oral esthetic and vascular treatments[7–12]

4.6 CO_2 laser properties 9600–10,600 nm (📷 4.23)

- It was one of the first lasers used in dentistry
- Active gas medium (CO_2), transported by hollow fibers or articulated arms
- Reaches nominal power of 5–10 W in continuous mode and electronically generated pulsed mode
- The emission at 9600 nm has a great affinity for hydroxyapatite, but generates a high thermal rise
- The emission at 10,600 nm has greater affinity with water; it is used for the treatment of soft tissues; produces precise and shallow incisions with little bleeding for the closure of blood and lymphatic vessels below millimeter[21]

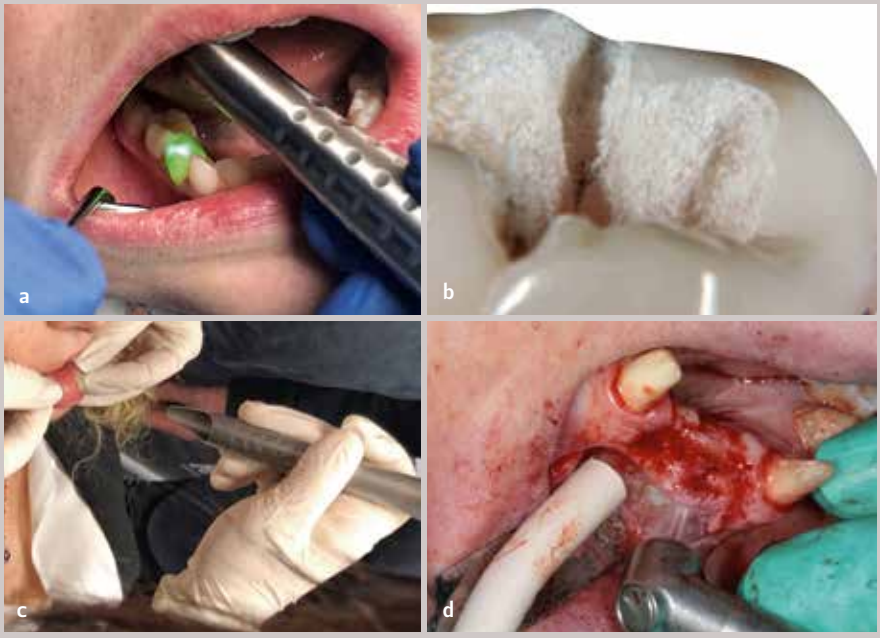


4.17 Versatility of using diode laser with different inserts. **(a,b)** Excision of a fibroid; **(c)** frenulectomy. **(d)** Hemangioma dehydration. (Courtesy of Dr. E. Romagnoli.) **(e)** Photobiomodulation.

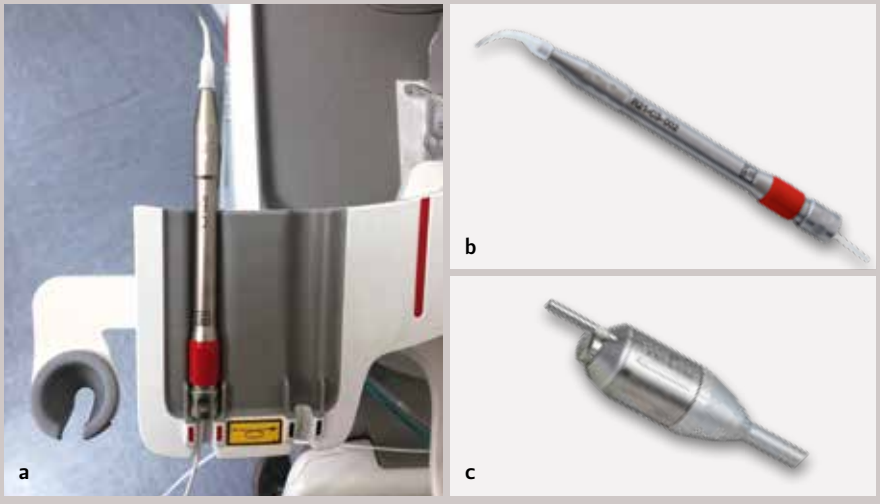


4.18 810 nm diode laser for biostimulation, surgical, vascular and dental applications with dedicated fibers, handpieces and tips. ORA-LASER D-LUX® (Oralia Costance, Germany. Rident, Italy).

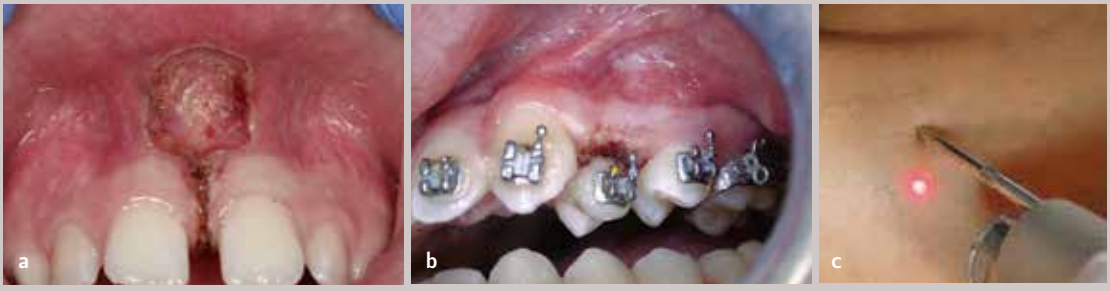
4.19 Er:YAG laser handpiece.



4.20 Applications of the Er:YAG laser. **(a)** Treatment of dental tissue with remote handpiece. **(b)** Detail of the preparation of the dental cavity. **(c)** Esthetic treatment with dermatological handpiece. **(d)** Treatment of bone tissue with handpiece and dedicated tip. (Courtesy of Dr. E. Romagnoli.)



4.21 Examples of Nd:YAG laser components. **(a)** Fiber with disposable handpiece and insert; **(b)** handpiece detail; **(c)** zoom handpiece for esthetic/dermatological treatments.



4.22 Applications of the Nd:YAG laser. **(a)** Frenulectomy; **(b)** gingivoplasty; **(c)** vascular treatment by dedicated handpiece.

Management, preparation, activation of optical fiber of diode laser

Optical fiber management

Optical fibers carry laser radiation from the equipment to the point of use ensuring minimal dissipation. In order to maintain signal strength, the material must be particularly transparent to the radiation transported (glass, silica). Unfortunately, this type of material is very fragile and can be worn and broken due to mechanical stress or accentuated curvatures. To ensure the best conductivity and mechanical protection it was wrapped in sheaths (4.24).

A very important safety check before use is the *verification of the integrity of the sheath*; a broken or cracked sheath can result, in addition to a decrease in the intensity of the laser beam, a dangerous radiation escape route.

The main parameters for the classification of optical fibers are as follows:

- diameter;
- power of use in Watts;
- color code depending on the use and type of applicator.

Optical fibers are connected to the equipment via a metal connector (4.25).

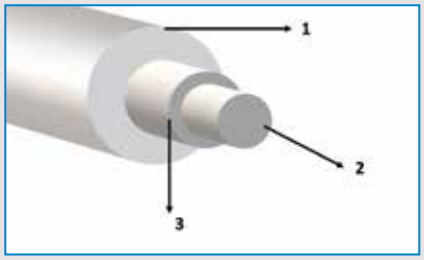
At the point of grafting, the connector typically has a thread or shaping to ensure coupling with the laser opening and better sealing. In addition, there is a micro switch on the laser opening, which allows the laser beam to be dispensed only if the fiber is properly inserted to avoid unexpected and dangerous emissions.

Upstream of the fiber, to retain dust and impurities, optical filters may be present, which must be kept clean to avoid deterioration of the beam, power losses and dangerous overheating (check the equipment manual for any procedures to be performed before use).

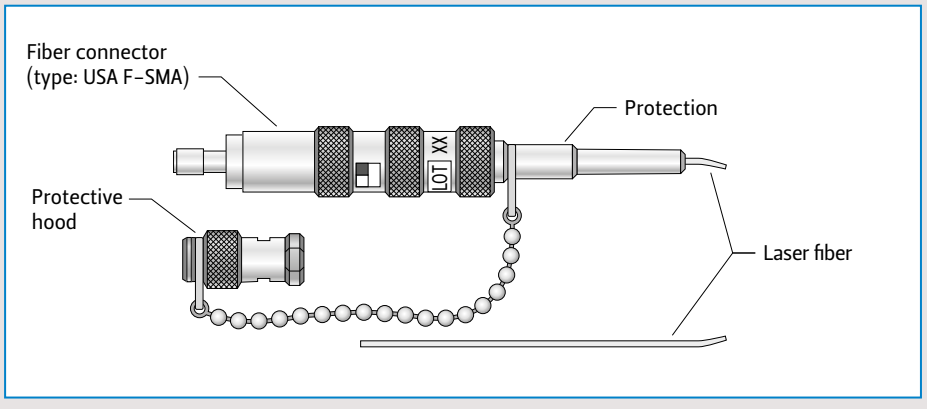
The distal tip of the fiber can be damaged or cracked; in this case, hot spots or deviations can be created in the direction of the beam. Periodically the perpendicular section (as transverse as possible) must be restored with a special cutter or ceramic blade. In addition, the protection sheaths must be removed in order to bring out the "naked" fiber for a sufficient length (generally a few millimeters), otherwise, in contact with the emerging laser beam, it can be charred or even ignited.

There are special precautions for the various stages of fiber management, which are summarized in Table 4.7.

4.23 CO_2 laser.



4.24 Example diagram of the structure of an optical fiber coated with sheaths (1: silicone outer coating, 2: fiber core, 3: cladding or inner lining closely glued to the fiber).



4.25 Example of a metal connector of optical fibers.

Pre-use steps of the diode laser in the dental field

The preparation for the use of the diode laser before a dental intervention includes, among the various necessary steps, the control of the operation of the laser components, the choice of the appropriate laser radiation conduction system, the choice of the appropriate handpiece and tip/insert (4.8).

The systems that use optical fiber for laser conduction, provide for the removal of the coating sheath and fiber protection before it can be activated, using special fiber-cutting and fiber-stripper tools (4.26 and 4.27).

Once the protective sheath is removed, the fiber is cut in its end part, taking care to obtain a clear and precise cutting margin, which will result in a rounded laser emission area with regular contours on the target tissue (4.28 and 4.29).

Subsequently, for cases that require it (for example, surgeries on oral soft tissues), optical fiber is activated (4.30).

Fiber activation is by sending a pulse lasting a few seconds to a dark surface, for example, a blue articulation map (4.31), resulting in the blackening of the end of the fiber (4.32). This allows a concentration of the energy emitted by the laser beam at the tip and reduces the energy transmitted in the deepest layers of the treated tissue [24].

4.7 Phases of laser fiber optic management

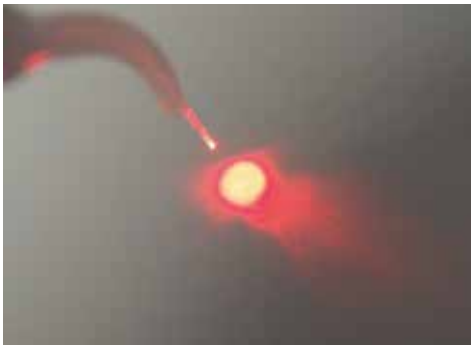
Precautions for use	· T conservation (15÷25 °C) · Dry environment · Protection from *direct light and heat* · Wrapped in a coil: radius › 10 cm
Pick-up and transport	· Dedicated container · Instrument fixed to the support plane · Safe transport
Fiber regeneration (with each use)	· Unsheathing · Cut · Distal tip inspection
Decontamination	· Dedicated solution preparation · Inserting the protective hood · Immersion of the probe · Contact time: 10 minutes
Manual washing and drying	· Wash with soft cloth · Rinse thoroughly · Last rinse with demineralized water · Drying with compressed air and soft cloths
Packaging and sterilization	· Perfectly dry fiber · Winding with radius 15-20 cm · Single pack · Tyvek envelope · Plasma gas sterilization

4.8 Preliminary operations for the proper functioning of the diode laser in dentistry

- Control of the operation of laser components
- Choice of conduction system
- Choice of tip/insert
- Removal of protective sheaths in the end of the optical fiber
- Cutting the optical fiber and controlling the spot of its terminal
- Activation of the fiber/tip (for cases that require it)

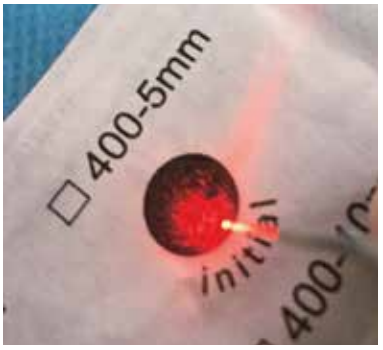
4.26 Fiber-cutting and fiber-stripper tools.

4.27 Special inputs for the optical fiber that allow it to be cut (to the right of the instrument) and the removal of the sheath (in the center of the instrument).



4.28 Properly performed fiber cutting results in a regular laser emission area.

4.29 Incorrect fiber cutting, with obvious irregularities of the laser beam.



4.30 Incorrect fiber cutting, with obvious irregularities of the laser beam.

4.31 Practical and economical kit for the activation and cleansing of optical fiber; this includes: a blue articulation paper for activation, gauze and a cotton roller for cleansing.

4.32 Activated optical fiber, which can be defined by the blackening of its terminal point.

REFERENCES

1. Grandofo M, Vecchia P. Laser radiation: Generation and Applications. Rapporto ISS L 82/8.
2. Benedicenti A. Atlante di Laserterapia, III edizione. Teamwork media, 2005.
3. Goldmann L, Rockwell RJ. Laser in medicine. New York: Gordon & Breach; 1971.
4. Maimann TH. Stimulated optical radiation in ruby. Nature 1960;187:493-4.
5. Stern RH. The Laser in dentistry: a review of the literature. J Dent Assoc S Afr 1974;29:173-9.
6. Goldmann L, Gray JA, Goldmann J, et al. Effects of laser beam impacts on teeth. J Am Dent Assoc 1965;70:601-6.
7. Goldmann L, Goldmann B, Van Lieu N. Current laser dentistry. Laser Surg Med 1987; 6(6):559-62.
8. Miserendino LJ, Neiburger EJ, Pick RM. Current status of laser in dentistry. Ill Dent J 1987 Jul; 56(4):254-7.
9. Meyers ML. The effects of laser irradiation on oral tissues. J Prosthet Dent 1991 Sep; 66(3):395-7.
10. Keller U, Hibst R. Effects of Er:YAG laser in caries treatment: A clinical pilot study. Laser Surg Med 1997;20(1):32-8.
11. Coluzzi DJ. Fundamentals of dental lasers: science and instruments. Dent Clin North Am 2004;48(4):751-70.
12. Miserendino L, Pick RM. Lasers in dentistry. Chicago: Quintessence Pub. Co.; 1995.
13. Goharkhay K, Moritz A, Wilder-Smith P, et al. Effects on oral soft tissue produced by a diode laser in vitro. Lasers Surg Med 1999; 25(5):401-6.
14. Pirnat S. Versatility of an 810 nm Diode Laser in Dentistry: An Overview- J Laser Health Acad 2007;4.
15. Dederich D N. Laser/tissue interaction: what happens to laser light when it strikes tissue? J Am Dent Assoc 1993; 124: 57-61.
16. Ball K A. Lasers: the perioperative challenge. 2nd ed., p. 19. St Louis: Mosby-Year Book; 1995.
17. Myers T D, Murphy D G, White J M, et al. Conservative 40. Soft tissue management with the low-powered pulsed Nd:YAG dental laser. Pract Periodont Aesthet Dent 1992; 4(41): 6-12.
18. Evans DJ, Matthews S, Pitts NB, et al. A clinical evaluation of an Erbium:Yag laser for dental cavity preparation. Br Dent J 2000 Jun 24;188(12):677-9.

19. Keller V, Hibst R. Ablative effect of an Er:YAG laser on enamel and dentin. Dtsch Zahnarztl, 44(8):600–2.

20. Eversole LR, Rizoiu IM. Preliminary investigations on the utility of an Erbium, Chromium YSGG Laser. J Calif Dent Assoc. 1995;23(12):41–7.

21. Fisher SE, Frame JW, Browne RM, et al. A comparative histological study of wound healing following CO2 laser and conventional surgical excision of canine 42. buccal mucosa. Arch Oral Biol 1983;28:287–91.

22. Rastegar S, Motamedi M, Jacques SL, et al. Theoretical analysis of equivalency of high-power diode laser (810 nm) and Nd:YAG laser (1064 nm) for coagulation of tissue. Predictions for prostate coagulation. [Proceedings of the Laser-Tissue Interaction 111. 21–24 Jan (1992). Los Angeles] Washington, Soc of Photo-Optical Instrumentation 44. Engineers.

23. Stubinger S, Saldamli B, Jurgens P, et al. Soft tissue surgery with the diode laser-theoretical and clinical aspects. Schweiz Monatsschr Zahnmed 2006;116(8):812–20.

24. Maggioni M, Attanasio T, Scarpelli F. I laser in odontoiatria. Padova: Piccin; 2009.