Laser-Assisted Restorative Dentistry (Hard Tissue: Carious Lesion Removal and Tooth Preparation)

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D.J. Coluzzi, S. Parker (eds.), *Lasers in Dentistry—Current Concepts*, Textbooks in Contemporary Dentistry,
DOI 10.1007/978-3-319-51944-9_8

Core Message

This chapter explores the range of benefits that relate to laser-assisted oral hard tissue management and details aspects of each wavelength in delivering adjunctive therapy. Of the currently available wavelengths of dental lasers, only three can be used for hard tissue.

- Erbium lasers available on the market can have two different wavelengths: 2940 nm (Er:YAG) and 2780 nm (Er,Cr:YSGG), and their use is gradually increasing in dental practices as an alternative or as a complementary tool versus traditional dental treatments.
- During the last 10 years, researchers have developed a CO_2 laser, traditionally used for soft tissue surgery, into a powerful hard tissue laser. The emission wavelength is 9300 nm, and the performance within clinical use in restorative dentistry is very promising.

▪ Table 8.1 shows Erbium laser advantages. These innovative properties can be easily perceived by comparing the use of these wavelengths and traditional techniques, envisaging the use of a high-speed handpiece and of a diamond bur, or alternative ones, for example, techniques such as air abrasion or the use of decayed material dissolving gels.

Thanks to its clear advantages, in restorative dentistry, every dentist can easily exploit the important characteristics that are revolutionizing dentistry.

This type of laser perfectly fits the minimally invasive dentistry philosophy. The experience reported by the patient during its use for cavity preparation is completely different from the one when dental drill is used to prepare a decay lesion (▪ Figs. 8.1, 8.2, and 8.3).

In most cases, local anesthesia through injection is not required, because erbium triggers an analgesic effect in just a few seconds. This laser allows pain-free ablation of hard tissues. Furthermore, no vibration is felt as the bur does not work in contact with the surface, and thus, the patient does not hear the traditional noise of the dental drill.

However, the operator has to go through a learning curve because the use of these wavelengths is neither intuitive nor immediate. A certain period of time is required to learn which is the optimal distance of the handpiece vis-à-vis the dental surface to be treated. By working contactless, it is indispensable to place the laser tip at about 1 mm in order to maximize ablation. Furthermore, the operator must have an in-depth knowledge on how to set and modify the various parameters (among which energy output, frequency of pulses, and the air/water ratio for cooling irrigation) [1].

However, high- or low-speed burs used with the dental drill are still more efficient and fast in removing dental tissues. Preparing a cavity by dental drill is much quicker.

Burs ensure optimal control, and their use is more intuitive as all dentists have been using them for ages and because

▪ Table 8.1 Table of hard tissue laser advantages

To be used on the hard tissues of the tooth, on the bone, and on soft tissues
Possibility to cut soft tissues at the same time during cavity preparation (i.e., gingivoplasty or pulp exposure treatment during conservative therapy)
Minimally invasive
Reduced or no need for local anesthesia
Suitable for preparation of very small cavities
Precision and accuracy in ablation on hard tissues
Limited risk of iatrogenic damages
Noiseless ablation compared to dental drill, no vibration, no contact
Ablation/excision selectivity of decayed hard tissues
Increased useful surface for bonding (micro-retentive surface)
Tissue decontamination
Biostimulation effect
No tissue/pulp heating
No hard tissue cracking
Limited coagulation effect on soft tissues
Working area on soft tissues stays clean
No smear layer in hard tissues

▪ Fig. 8.1 Small cavity preparation on tooth #2 (Er,Cr:YSGG Waterlase iPlus laser with wavelength of 2780 nm by Biolase Technology, Irvine, CA, USA). Enamel settings: MGGG6 sapphire tip diameter 600 µm, length 9 mm, 3 W, 15 Hz, 200 mJ E per pulse, peak power 3333 W, average power density 492 W/cm^2, peak power density 546.710 W/cm^2, total energy 90 J, pulse width 60 µs, 1 mm tip-to-tissue distance, 50% water (18 ml/min), 80% air. Dentin and smear layer settings: MGGG6 sapphire tip diameter 600 µm, length 9 mm, 2 W, 15 Hz, 133 mJ E per pulse, peak power 2222 W, average power density 328 W/cm^2, peak power density 364.473 W/cm^2, total energy 20 J, pulse width 60 µs, 1 mm tip-to-tissue distance, 50% water (20 ml/min), 80% air. Parameters calculation made according to Prof. W. Selting indications

Fig. 8.2 Detail of completed preparation of tooth #2

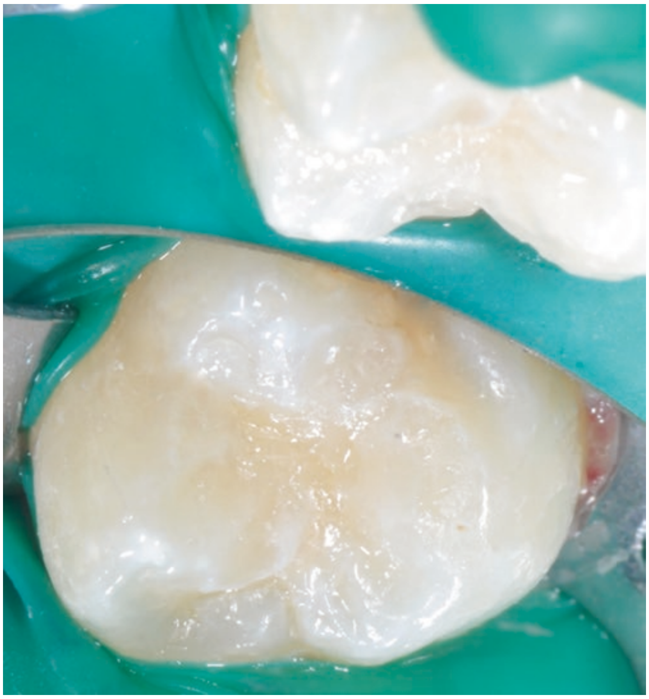

Fig. 8.3 Completed composite restoration in tooth #2 (acid etching with orthophosphoric acid 37%, OptiBond FL total-etch adhesive system (Kerr, Orange, CA, USA), composite material Herculite XRV Unidose (Kerr, Orange, CA, USA))

they received thorough training on their use. At the same time, however, burs are more aggressive and nonselective; they generate intense vibration which may be harmful to the tooth structure, and they may cause cracking and pulp heat damage.

Furthermore, during their use, a large amount of smear layer is produced requiring acid etching for its removal before the application of the chosen adhesive system.

Table 8.2 Comparison bur vs erbium laser

Restorative procedure	Handpiece and bur	Laser
Cutting enamel/dentin	Yes	Yes
Selective removal of caries	No	Yes
Precision	Precise >1–2 mm	Precise <300 µm
Smear layer	Smear layer produced	No smear layer
Thermal rise	Thermal rise >15 °C	Thermal rise <5 °C
Risk of iatrogenic damage	Greater	Less
Noise/vibration	120 dB/vibration	< 120 dB/no vibration
Bactericidal action	No	Surface decontamination
Speed of cutting enamel	Fast	<30% bur speed
Speed of cutting dentine	Fast	Comparable
Pain response	High	Less pain/no pain

Very frequently it is necessary to use local anesthesia by injection in order to avoid pain to the patients. The traditional technique is at the basis of the intense fear and phobia that patients feel when they have to undergo conservative therapy.

Table 8.2 shows a comparison among the characteristics resulting from the use of the traditional high-speed handpiece with diamond bur vis-à-vis the use of the erbium laser [2].

An alternative more delicate method, and less aggressive too, is represented by air abrasion, exploiting aluminum oxide particles (Al_2O_3) to remove carious tissues.

With this method, the risk of cracking is lower than with the one using the diamond bur, and no smear layer is produced. Adhesion of composite seems increased thanks to the created micro-irregularities and, as a consequence, we will have less microleakage.

The main disadvantage is represented by the particle layer that is deposited on the entire working area, which must be accurately removed before starting any adhesive technique.

Decay chemical and mechanical removal systems envisage the use of sodium hypochlorite type of chemical substances (usually in the form of gel) or of enzymatic type. These substances can selectively dissolve decayed tissues, which are then removed through excavating tools.

Fig. 8.4 Fracture of tooth #13 crown

8.1 Effect on Hard and Soft Tissues

An additional advantage resulting from the use of the erbium laser compared to other methods is represented by the intraoperative possibility of performing ablation/excision of hard tissues and at the same time of treating surrounding soft tissues by gingivoplasty, a more extensive gingivectomy, or also the clinical crown lengthening which simultaneously modifies gum levels and possibly the bone margin by restoring the lost biological width (Figs. 8.4 and 8.5).

In fact, if during decay preparation it is required to expose the healthy edge of the cavity, temporarily covered by the gum, it is very easy to perform a light gingivoplasty in order to remove the superfluous keratinized tissue.

Should it be required to remove the excessive gum margin due to the size of the decayed cavity, it is possible to perform such procedure during the same conservative therapy session by simultaneously removing decayed and soft tissues.

If the correct biological width is lost, performing the lengthening of the clinical crown with regard to soft tissues is very quick and possibly also including the underlying bone tissue.

The entire procedure can be completed in a single session by considerably reducing operative times.

Erbium lasers have moderate control over bleeding when used at low energy values, high frequency (30–40 Hz), with a high pulse width (i.e., 700 µs/pulse), without water, and little cooling air to facilitate thermal interaction with tissues.

Fig. 8.5 Gingivectomy and crown lengthening of tooth #13 (Er,Cr:YSGG Waterlase iPlus laser with wavelength of 2780 nm by Biolase Technology, Irvine, CA, USA). Gingivectomy settings: MT4 sapphire tip diameter 400 µm, length 6 mm, 2.5 W, 25 Hz, 100 mJ E per pulse, peak power 1667 W, average power density 1989 W/cm^2, peak power density 1.326.292 W/cm^2, total energy 300 J, pulse width 60 µs, in contact, 40% water (16 ml/min), 20% air. Crown lengthening settings: MZ6 quartz tip diameter 600 µm, length 9 mm, 4 W, 25 Hz, 160 mJ E per pulse, peak power 2667 W, average power density 656 W/cm^2, peak power density 437.368 W/cm^2, total energy 480 J, pulse width 60 µs, tip-to-tissue distance 1 mm, 60% water (20 ml/min), 80% air

This is a characteristic that can be used in conservative dentistry, as well as in oral surgery and dental prosthetics to facilitate hemostasis.

If necessary, should the pulp be exposed following a trauma or penetrating decay, it can be decontaminated and coagulated before performing pulp capping or selective pulpotomy.

8.2 Affinity with Water

Both erbium laser wavelengths (2780 and 2940 nm) have high affinity with water [3, 4]. In fact, they are both almost fully absorbed by this molecule (the second one even to a greater extent so).

The highest the content of water in the tissue, the greater the absorption will be.

Considering that the laser beam penetration is inversely proportional to absorption, impulses do not spread much in depth; thus, the beam can penetrate dental tissues by only a few microns (for the wavelength of 2940 nm, it is 7 µm into the enamel and 5 µm into the dentin, while for the wavelength of 2780 nm, it is 21 µm into the enamel and 15 µm into the dentin) [5–9].

If the tissue has high water content (i.e., soft tissues vs hard tissues, dentin vs enamel, deciduous dentin vs permanent one, decayed dentin vs healthy dentin), the energy of erbium lasers could more easily cause explosive ablation at lower energy levels. The average threshold level at which ablation of hard tissues occurs is about 8–11 J/cm^2 for the Er:YAG laser and about 10–14 J/cm^2 for the Er,Cr:YSGG laser [8].

This phenomenon is at the basis of selective ablation. Erbium more easily removes the most hydrated tissue vis-à-vis the one with the lowest water content; thus, it is more effective on decayed dentin, and it saves the healthy tissue surrounding it.

This is the reason why laser parameters will have to be adjusted according to water content, for example, by reducing the beam energy used for a deciduous tooth vs what one would do to perform the ablation of a permanent tooth.

If the level of energy is sufficient to remove the carious tissue, but not the healthy one, it is perfectly useless, and actually it is rather harmful, to increase it, as one would risk to excise part of the healthy tooth.

The energy threshold value that can allow a clinically efficient ablation of hard dental tissues is:

About 125 mJ (100–150 mJ) for primary dentin and decayed tissues
About 150 mJ (100–200 mJ) for permanent dentin and primary enamel
About 225 mJ (200–250 mJ) for permanent enamel

With regard to posterior teeth, or if tissues are highly calcified and with less water content, it could be necessary to further increase energy parameters (up to about 350 mJ for healthy enamel).

8.3 The Level of Laser Energy

Erbium lasers are equipped with external integrated irrigation systems through an air/water spray. This allows to cool off targeted tissues, to keep the working area clean as it is key to prevent damages and thermal alterations on the cavity surface and on the tooth pulp.

The operator should be able to accurately choose laser parameters in order to efficiently perform the ablation without damaging the surrounding healthy tissues.

The first decisive factor is represented by the level of laser energy. It is always good practice to use minimum efficient value to obtain adequate excision. Excessive energy may damage the dental surface by altering, for example, the possibility of performing a good adhesive technique of composites [10].

The chosen energy level can also be addressed toward a smaller or bigger surface. If the chosen level of energy is spread on a small surface, it will be easier to obtain the ablation effect vis-à-vis when the energy is spread on a bigger surface [11].

In fact, if the same amount of energy is spread on a bigger surface, the amount of energy per surface unit will be smaller.

Its density (energy density or fluence) could be unsuitable to achieve the threshold level capable of interacting with a tissue by inducing its excision.

By placing the tip in contact with the tissue, fluence will be maximum, while by increasing the distance, we reduce it by about 70% at 0.5 mm, by 52% at 1 mm, by 32% at 2 mm, by 22% at 3 mm, and so forth. Obviously, the greater the energy density, the greater the interaction between laser and target tissue.

Furthermore, this parameter can change, for example, by using a fiber or a tip with a different diameter. If the tip diameter is bigger, the energy is released and spread over a larger target surface compared to a tip with a smaller diameter.

Thus, the subsequent effect will be smaller. The removal of a tissue occurs with a specific level of energy starting from the «threshold» value. Below it, no excision will occur, but there could be important structural or microstructural modifications [12–15].

On the other hand, above the threshold of 150–200 mJ, there would be a proportional increase of the excision, but also an increase in the risk of structural thermal alterations, especially if the air/water spray cooling is insufficient [16–18].

In such event, these alterations concern a depth of a few tenths of microns.

The used energy is measured in joule (J) and its density in J/cm^2.

8.4 Pulses and Frequency

Erbium lasers operate by free-running pulse (FRP), i.e., by releasing energy pulses alternated by moments in which the energy is not released, and they are repeated several times every second.

The number of pulses released every second is called frequency (or pulse frequency). This value is expressed in hertz (Hz or p.p.s., i.e., pulses per second).

The larger the number of pulses in the time unit, the larger and quicker the interaction with the target tissue will be, because a larger amount of energy is transferred to it.

The amount of energy that is released in the time unit identifies the power, i.e., the energy of each pulse times the number of pulses per second. It is measured in watt (W).

Thus, power depends on the ratio between energy and the number of pulses per second (W = J × Hz).

When energy is provided through a short pulse (a pulse duration of about 50–150 µs), you get a high amount of energy which interacts with the tissue in a fraction of a second, and this means achieving huge power value.

Each pulse can, however, achieve a maximum power (peak power) which has a major impact on the tissue. Interaction with a target is greater if the peak power is high. The shorter the pulse duration, the lower the energy converted into heat will be. As a consequence, thermal interaction and the damages to the teeth tissues following temperature increase will be reduced.

The irradiated enamel and dentin surfaces after interaction with the laser present valleys and peaks, deeper ones when the applied energy is higher.

The appearance is very similar to that of etched tooth tissues: without smear layer, clean, wavy, micro-rough, and irregular.

Fig. 8.6 Preparation of a class I cavity in tooth #14 (Er,Cr:YSGG Waterlase iPlus laser with wavelength of 2780 nm by Biolase Technology, Irvine, CA, USA). Enamel settings: MZ6 quartz tip diameter 600 μm, length 9 mm, 3 W, 15 Hz, 200 mJ E per pulse, peak power 3333 W, average power density 492 W/cm^2, peak power density 546.710 W/cm^2, total energy 90 J, pulse width 60 μs, 1 mm tip-to-tissue distance, 50% water (18 ml/min), 80% air. Dentin and smear layer settings: MZ6 quartz tip with diameter of 600 μ, length 9 mm, 2 W, 15 Hz, 133 mJ E per pulse, peak power 2222 W, average power density 328 W/cm^2, peak power density 364.473 W/cm^2, total energy 20 J, pulse width 60 μs, 1 mm tip-to-tissue distance, 50% water (20 ml/min), 80% air

Dentin, in particular, has open tubules, and it is subjected to a major excision in the intertubular area as it is very hydrated, while peritubular areas are more elevated and protruded.

8.5 Distance to the Target

It is key that the operator works by holding the laser handpiece at the correct distance from the target in order to optimize excision and treatment duration. Since the laser is contactless, excessive distance prevents the efficient interaction with tissues.

Furthermore, the hand holding the handpiece must move slowly to allow the laser energy to interact with the tissue. The speed of the movement must be slower than the speed normally used with the dental drill.

During a cavity preparation work (Figs. 8.6 and 8.7), the tip is gradually inclined on one side to obtain widening [19].

Fig. 8.7 Inclination of the tip toward the walls of the cavity during carious tissues ablation in tooth #14

As preparation proceeds, the tip must be positioned deeper to maintain the ideal distance vis-à-vis the target and thus obtain a high and continuous energy density.

8.6 The Problem of Laser Etching

The use of energy values below the ablation threshold (subablative) allowing a microstructural modification in dentin and enamel creates a very similar surface to that obtained with orthophosphoric acid. Improperly, this effect has been long defined «laser etching» in literature [20–27].

The differences between acid etching and surface etching by erbium laser are numerous. More precisely, it would be appropriate to use the term «laser conditioning» [28, 29].

Acid etching is a process that has been used for decades to facilitate composite adhesion. Even though there are some issues associated with it (excessive decalcification with alteration of the enamel-dentin ideal architecture for adhesion, higher susceptibility to secondary decay, tooth sensitivity, excessive demineralization compared to the penetration ability of adhesive system monomers), the results obtainable through orthophosphoric acid are widely predictable [30–32].

With regard to the use of orthophosphoric acid at 34–38%, erbium lasers generate a more irregular surface; the greater the energy and the lesser the frequency, we, respectively, get deeper and more far-apart craters.

Even if the final surface is very similar to the etched one, composite adhesion process to irradiated tooth hard tissues is a controversial phenomenon, and its outcome should be further investigated as many authors deemed it of lower quality.

In literature, data are quite contrasting, and, often times, adhesion values came out much lower than those obtainable with the acid [25, 26, 33–37].

8.7 Microleakage

Difficulties encountered by operators during the bonding procedure between the composite and hard tooth tissues often translate into microleakages or the complete detachment of the reconstruction from its seat [38].

Microleakages can be defined as a loss of marginal seal between the restorative material used for tooth filling and the tooth cavity wall with the subsequent infiltration of bacteria, fluids, molecules, or ions [39–42].

Among the causes of microleakage, we can mainly keep the following elements into account:

1. Incomplete penetration of the bonding resin in the area that was decalcified by the etching acid or following the erbium laser effect. This gives rise to the formation of a weaker bonding area, which will be more sensitive to hydrolysis and infiltration.
2. Stress generated at tooth/reconstruction interface level following polymerization shrinkage, or due to oral environment temperature fluctuations [43], or due to cyclical phenomena of mechanical fatigue that are repeated during the masticatory load.

Infiltration of bacteria or of fluids along the interface can cause hydrolytic collapse, both of the adhesive resin and of the collagen present in the hybrid layer, jeopardizing bond stability between the resin and the dentin surface.

Microleakage is the main factor of secondary decay and of reconstruction failure [44–46], and it is at the basis of dentin hypersensitivity, discoloration, and pulp damages.

An additional cause of detachment between composite and tooth wall is related to the shape of the prepared cavity. The greater the number of walls (i.e., box-shaped cavities typical of class I of Black's classification), the greater the relationship between bonded surfaces and nonbonded ones. This principle is defined as C-factor [47, 48].

If the entire composite simultaneously adheres to the walls, as it happens in the occlusal cavities of molars, there will be many more cases of shrinkage-related stress because the composite adhering to many walls at the same time, by contacting, generates even greater stresses.

On the other hand, if cavity tooth walls are just a few (i.e., interproximal preparations of class II premolars and molars), we would assist to reduced stress since the part of nonadhering materials can compensate for polymerization shrinkage, releasing the effects toward the part free from constraints, and thus, there will be lesser risk of reconstruction detachment.

Insufficient compensation of stresses resulting from polymerization shrinkage reduces the efficiency of the seal due to the reduced initial strength of the composite-cervical dentin bond.

The larger marginal gap is usually located on class V gingival side and on the external edge of the class II gingival margin (V-shaped gap). This is due to a lesser capacity of the dentin sublayer and of cement at the tooth neck to favor strong bonding with the resin by means of an adhesive system [33, 49, 50].

Width gap below about 1 μ does not allow bacteria infiltration, but it may allow the spreading of toxins and of other tooth potentially dangerous bacteria-related substances (nanoleakage).

When the cervical margin is located on the limit line between root dentin and cement, the leakage problem becomes more relevant because adhesive systems become less efficient at the level of these substrates vis-à-vis when they are used on the enamel. The bonding process to dentin is much more technique-sensitive and substrate-sensitive.

The ability of adhesive systems to bind to hybridized cementum must be discussed. «Cervical margin leakage can be correlated to the absence of dentin tubules in 100 μ within the cervical border itself, to the relatively reduced number of tubules in the first 200–300 μ of the gingival floor in the cavity, and to the mainly organic nature of the gingival substrate» [51].

When present in the cervical margin, enamel is usually thin, aprismatic, and less receptive to bonding.

When polymerized, composite resin shrinks toward the upper adhesion site of the occlusal cavity margin, while it gets far apart from the weakest adhesion placed at the gingival margin level.

8.8 How to Increase Adhesion

In order to obtain better bonding conditions and facilitate monomers' spreading within the demineralized intertubular dentin, which was altered by laser irradiation, different post-irradiation dentin pretreatments have been suggested for adhesion procedure.

Among them, we point out the use of:

- Sodium hypochlorite at a concentration ranging between 5% and 10%
- Orthophosphoric acid at 33–38% with an extended etching time [52]
- Polyacrylic acid (for glass ionomer material)
- Chlorhexidine gluconate
- Propolis
- Hydrogen Peroxide
- Ozone gas

Sodium hypochlorite can be used to remove collagen fiber frustules and dentin fragments modified by laser interaction. In such a way, following its use, we obtain a clean surface, free from the alterations produced during laser use (even if, thanks to the erbium laser, as we have already flagged out, there is no smear layer).

The extension of the etching time by orthophosphoric acid apparently does not promote better adhesion, but, on the contrary, it can generate an excessively etched tooth surface. It is appropriate to consider that the irradiated tooth surface does not have smear layer, because the erbium laser does not produce it, unlike what happens when using the high-speed handpiece and the diamond bur. For this reason, by performing the etching on hard tooth tissues, we obtain an immediate contact between acid and intra- and peritubular dentin. An excessive contact between acid and tubules could, on the contrary of what we would desire, completely destroy the dentin architecture favorable adhesion.

Most recent clinical recommendations advise enamel etching not exceeding 30 s and a very limited acid treatment on dentin.

There is no certain clinical proof that the different pretreatments listed here could improve the action of adhesive systems for composites.

According to Arslan S. et al. [53], «No adverse effect of different cavity disinfectants on microleakage were found when etch-and-rinse adhesive system was used.»

8.9 Why Adhesion Can Be Impaired

There are different possible explanations on why the composite adhesion strength to the irradiated dentin could be lower than the one achieved through phosphoric acid.

Different researchers believe that the main mechanism causing insufficient bonding between irradiated dentin and composite is the collapse and/or melting of collagen fiber network during laser excision [54].

In fact, the considerable increase of temperature following irradiation causing the instantaneous vaporization of the water component of the mineralized tooth matrix and of collagen fibers, initially spread and supported in this framework, tends to collapse because they are no longer supported by the crystalline structure. The consequence will be a reduction of bonding spreading within the network because the interfibrillar structure is reduced. Thus, the hybrid layer will not be of optimal quality for adhesive procedures [54].

Ablation of dentin melts collagen fibrils together, resulting in a lack of interfibrillar space that restricts resin diffusion into the subsurface of intertubular dentin, causing a lack of penetration of the resin and even a possible peeling off of the resin layer from the ablated dentin surface [55–58].

Erbium lasers used with excessive parameters can furthermore have a harmful effect on hard tissues. Too high laser energy values can cause cracking in tooth dental tissues, surface melting, surface scaling and flacking, marked loss of intertubular dentin, and collagen melting [54, 55].

It has also been thought that pulses could generate intense elastic waves inside tooth hard tissues during excision as a result of the interaction with the laser beam and due to alternate thermal expansion and shrinkage.

By occurring inside a hard and stiff tissue, stress waves could cause micro-cracking and fractures in the dentin thickness and at the dentin/composite interface level, negatively affecting adhesion strength [1, 58, 59].

An additional explanation of the weaker bond between composite and dentin is represented by the deep craters that are created when laser energy is high: these valleys/hollows can prevent the optimal adaptation of the reconstruction material to the cavity walls since the resin would not be able to fill deeper concavities [60].

Furthermore, there could be an uneven distribution of the masticatory stress at adhesive-dentin interface [54, 61, 62].

Dunn et al. [34] as well underlined that «Laser irradiation of enamel surfaces produced surface fissures and a union or blending of a distinctive etch pattern normally seen in acid-etched enamel. This blending effect likely prevented the penetration of resin into enamel, resulting in lower enamel bond strength values.

It is very important that at the end of cavity preparation, unsupported enamel margins are removed, and margins are smoothed. This operation can be done at low-power and high-speed Er:YAG or Er,Cr:YSGG laser, or with hand tools (enamel cutter, excavators) or low- or high-speed tools with diamond or lamellar burs, or rubber tips [63] (◘ Figs. 8.8, 8.9, 8.10, 8.11, and 8.12).

◘ **Fig. 8.8** The crowns of these anterior teeth are severely abraded

◘ **Fig. 8.9** The margins of abraded crowns are rounded thanks to laser irradiation (Er,Cr:YSGG Waterlase iPlus laser with wavelength of 2780 nm by Biolase Technology, Irvine, CA, USA). Enamel settings: MZ5 quartz tip diameter 550 μm, length 9 mm, 2.5 W, 30 Hz, 83 mJ E per pulse, peak power 1389 W, average power density 461 W/cm^2, peak power density 256.030 W/cm^2, total energy 75 J, pulse width 60 μs, 1 mm tip-to-tissue distance, 50% water (20 ml/min), 80% air

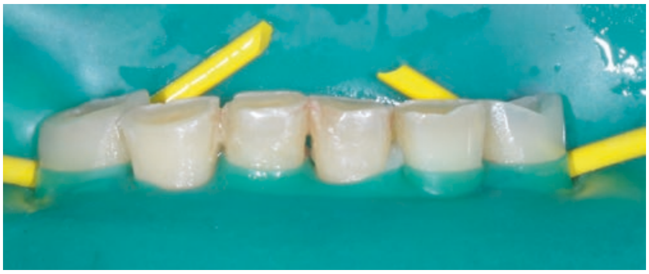

Fig. 8.10 Isolation with dam

Fig. 8.11 Acid etching with orthophosphoric acid 37%

Fig. 8.12 Finished restoration of anterior teeth (adhesive system OptiBond FL total-etch adhesive system (Kerr, Orange, CA, USA), composite material Herculite XRV Unidose (Kerr, Orange CA, USA))

Forgetting this step may result in a diminished wall strength; it may cause incomplete adaptation of the composite to the preparation margin and a subsequent chipping of the reconstruction margin and/or the enamel subjected to the masticatory load with subsequent microleakage.

Recent researches took into account the possibility that during irradiation by erbium laser, calcium phosphate insoluble molecules could be formed, which would prevent optimal composite adhesion [54].

On the other hand, authors believe that collagen denaturation during ablation causes an acid-resistant surface containing charred granular structures or structures covered with melted dentin particles. This denaturation could jeopardize infiltration of the adhesive system into the dentin structure, and it could prevent the creation of the hybrid layer [58, 64].

Such phenomenon could concern cement during classes II and V cavity preparation, because «When cement is reached by erbium irradiation, it is altered and a thin layer (5.7 μm) is formed. This can hamper hybridization because it becomes less affected by acid etching» [65].

If the resin cannot efficiently infiltrate into intra- and peritubular dentin, we could only obtain shorter resin tags, without funnel-shaped morphology and lateral resin projections, and this would entail a damage to the resulting adhesion [57, 66, 67].

When using this type of laser, the absence of the smear layer, which is instead inevitably created during cavity preparation with burs, allows the immediate exposure of dentinal tubules and accentuates their permeability to dentin adhesives. Furthermore, the absence of smear plugs allows the passage of intratubular fluids to and from the pulp [68].

«Loss of smear layer due to laser irradiation exposes the dentinal tubules and enhances the permeability of dentin adhesives. Intrinsic dentin wetness, as affected by pulpal pressure, could also affect the hydration state of dentin and the bond strength to dentin adhesives. Laser affects fluid perfusion of dentin more than bur.»

It is important to keep into account the fact that greater perfusion could make dentin more moist, and for that reason, it may interfere with some adhesive systems, especially water-based ones which could end up being more diluted.

The best way to avoid or minimize the impact of these surface alterations which may cause difficulties to achieve optimal bonding is to reduce the laser energy for ablation to the lowest efficient level, compatibly with the time required to completely remove the decay.

Many authors [69] agree on the fact that after irradiation, it is however preferable to perform enamel acid etching by orthophosphoric acid in order to obtain an even micro-rough surface. Enamel laser conditioning, on the other hand, would not be useful.

The use of an acid on the dentin could be positive as it would allow the removal of the top layer altered by the erbium laser and exposes the network of collagen fibers which make up the ideal matrix required to create the hybrid layer for the bonding process. However, researchers' opinions are quite contrasting.

Thus, although different acid application times are suggested, it would be appropriate not to exceed 30 s of contact time on the enamel and 15 s on irradiated dentin.

It is advisable to remember that since the smear layer is absent, phosphoric acid acts more rapidly on the mineralized crystalline structure of hard tooth tissues, in particular on peritubular and intertubular dentin, and on collagen fibers.

Other authors [70] advise to etch irradiated enamel for max 15 s and to avoid acid treatment on dentin at all.

8.10 Adhesive Systems for Irradiated Hard Tissues

An extensive discussion has been going on for quite some time on the opportunity of completely eliminating the smear layer (etch-and-rinse technique, Total Etch) or to modify it through suitable self-etch adhesive systems which would only remove one part of it and then maintain and exploit the remaining part of it to create suitable substrate for bonding [59, 71–83].

With regard to adhesion between composite materials and irradiated dentin, researches are still debating if it would be possible to obtain optimal bonding through an etch-and-rinse or through self-etch adhesive systems. Results described in the most recent literature are extremely contrasting and contradictory. For the time being, the most advised therapeutic attitude with regard to the adhesive system is to adopt the same procedures that are normally used for tooth tissues treated by diamond burs. The combination between orthophosphoric acid and fourth-generation adhesive with two steps (three-step etch-and-rinse) still provides a very good bond between composite and tooth, also in case of erbium laser treatment. However, the enamel must be treated with acid etching for 15–30 s. At dentinal level, the result seems even better thanks to the sixth-generation self-etch adhesive (two-step self-etch adhesive). This system can also be used on irradiated enamel, however, after acid etching.

Irradiated dentin, but yet directly etched with acid, can be laser conditioned, provided that low energy values and low power are used (40–50 mJ), for a short period of time and with a considerable amount of water for cooling [84].

8.11 Decontamination Effect

One big advantage in laser dentistry is represented by the decontamination effect of tissues. Also during a restorative treatment, the operator performs dentin disinfection by vaporizing water of bacteria (bactericidal action), thus decontaminating the cavity [85–88].

Bacteria below surface are killed during laser cavity preparation to a depth of 300–400 μ. [89]. This means that the hard tissues treated with this wavelength have an important microorganism count reduction in the irradiated layers.

8.12 Effect on Tissue Temperature

The energy generated by the erbium laser can be so powerful to break down the crystalline structure of hard tissues of the human body; however, if the used energy levels do not excessively exceed excision threshold limits, they can be much less aggressive than the diamond bur used on a high-speed drill.

In fact, the vibration and pressure exercised by using a traditional technique can very easily create microfractures that branch out on the prepared decayed cavity walls. These will later on give rise to sensitivity, pain to heat/cold stimulation, risk of pulp infiltration damages, and secondary decay, till causing reconstruction failure.

If the erbium laser is used with the adequate selected parameters (i.e., low energy and frequency), sufficient enough to obtain decay ablation without creating any trauma inside the tissues, cracking will not occur.

The very high water absorption coefficient for the two erbium laser wavelengths allows to limit the penetration of the beam by just a few microns (7 μ in the enamel and 5 μ in the dentin for Er:YAG 2940 nm, 21 μ in the enamel and 15 μ in the dentin for the Er,Cr:YSGG 2780 nm) [5–9].

This limited penetration, especially if combined to a very short pulse width, allows a very limited transfer of heat into tissues. With optimal cooling made by an integrated air/water spray, temperature increase at pulp level will be below 5 °C [90–93].

On average, in fact, there is a temperature increase by 1–2 °C in the pulp chamber, while the use of a high-speed bur entails a more frequent potential heat damage, especially in cavities where the floor is in close proximity with a pulp horn.

It is obviously indispensable to use energy levels compatible with efficient excision and without being excessively traumatic or harmful for the tooth architecture.

8.13 The Cooling

It is also equally important to use a cooling spray with a water amount and an air volume sufficient to remove the fragments created during irradiation and cool the treated surface quickly.

The minimum amount of water which should be used is of at least 8 ml/min, but it would be better if it could be doubled. Not all erbium lasers available on the market accurately show on the display the amount of used water. Oftentimes, the display only shows a percentage vis-à-vis the 100% capability that can be held in the handpiece. However, the maximum value depends on the pressure present in the local aqueduct water network or in the building where the dental practice is, depending on manufacturer's settings and also depending on the setting of the individual laser entered by the installer. In order not to run the risk of using an insufficient amount, it is advisable that the operator personally measures how much water per minute is delivered by the handpiece in percentages of 10, 20, 50, and 100. In this way, we can be aware of how much water is used, and thus, we can be sure of not overheating tissues and avoid thermal damages which could cause tooth pulp necrosis, a phenomenon of dental hypersensitivity, or alter the tooth surface with subsequent worsening of composite adhesion.

8.14 The Welding Effect

It is also possible to select a cooling spray containing a reduced amount of water when more thermal interaction is required. This type of use, which can modify the tooth surface, is called «welding,» and it may allow to reduce dentinal sensitivity and can transform the outer tooth wall, especially at tooth neck level or in case of preparation of a fixed prosthetic, in order to be more resistant to acids produced by decay-inducing bacteria and less permeable. The microstructural effect, in fact, is represented by the obliteration of dentinal tubules by the melting of the dentin outer layer and coagulation of collagen fibers.

This procedure must be performed with low energy levels and for very short treatment periods, otherwise it is possible to cause severe pulp damage due to temperature increase.

8.15 Laser Analgesia

Use at low energy level and power allows to achieve one of the most important advantages that can be obtained through this laser in conservative dentistry: laser analgesia. In fact, erbium wavelengths allow cavity preparation also in deep dentin, without the need to perform local anesthesia by injection and without causing pain to the patient.

This is possible in a wide variety of cases [94], and it is also very useful in pediatric dentistry, for phobic patients, for all those patients who do not like injections, and for those who are allergic to local anesthetics.

Any dentist knows that the fear for needles discourages many patients to go see a dentist [95].

Vibrations, pain, and noise perceived when using the bur or the drill contribute to worsening the fear which is very frequently associated to dental care. In fact, all of this may trigger anxiety before dental treatments. Besides fear, the patient can report correlated psychosomatic symptoms (dyspnea, tachycardia, sense of suffocation or light head, etc.) which may involve the possibility of not treating the patient or cause real discomfort and emergencies on the patient chair.

Furthermore, anxious patients counteract the treatment by refusing it or by not collaborating.

The clinical situation and the symptomatology get further complicated if the subject is «dental phobic,» as extreme anxiety toward dental cares will grow exponentially.

It is believed that dental phobia affects 4–16% of adults and 6.7–20% of children [96, 97]. Its incidence tends to lower with age, but it may persist among the elderly.

Thus, anxious patients are treated with extreme difficulty.

The absence of rotating instruments, with discomfort due to vibrations and noises, and of local anesthesia can facilitate the interaction between patient and dentist. In this way, in fact, two important factors setting off anxiety are removed. Dentists must be able to identify and treat afraid patients in order to lower their anxiety level [98, 99].

8.16 Alternatives to Local Anesthesia for Cavity Preparation

Which are the possible alternatives available for a clinician to avoid the use of the two therapeutic options so much opposed by patients?

The methods that can somehow substitute local anesthesia for pain control during dental care include techniques with different degrees of probability of success and different abilities of anxiety and pain attenuation or suppression.

Possible therapeutic alternatives designed to minimize fear and anxiety toward traditional dental treatments include hypnosis, conscious sedation with a mixture of nitrous oxide and oxygen, electronic anesthesia or electrostimulation, high absorption coefficient topical anesthesia, general anesthesia, conscious sedation with oral drugs or by intravenous injection, and by using the erbium laser.

Each one of the above listed techniques has pros and cons. None of them has a 100% success rate to eliminate anxiety and to facilitate patient compliance. Unfortunately, none of them allows to perform a painless treatment, free from discomfort for all patients; furthermore, some of them could have side effects and/or potential risks.

It has been known for decades (or better, for hundreds of years) that achieving hypnosis status may allow to perform medical therapies, even very invasive ones (delivery, endoscopy, surgery) without any pain. In dentistry, for example, it is possible to perform wisdom teeth extraction without any pain whatsoever.

Not every patient, however, reaches a sufficiently deep level of trance able to obtain the hypnotic analgesia. Hypnosis, then, can be considered more helpful for its calming potential and to improve patient compliance.

Conscious sedation with nitrous oxide and oxygen is based on the inhalation of a mixture of nitrous oxide and oxygen gases in variable proportions using a nose mask. This mix reduces anxiety, it has a euphoric effect, it is lightly analgesic and reduces tissue sensitivity, and it gives a mild retroactive amnesia and a feeling of well-being and reduces the perception of time. With a customizable proportion of the two gases (on average, 20–50% of nitrous oxide and 80–50% of oxygen), after 3–5 min, it is possible to obtain the desired effect and maintain it for all the time needed.

Discontinuation of the mixture administration and the delivery of 100% oxygen allows the disappearance of the previous symptoms within few tens of seconds. This system, however, cannot allow to obtain a true and complete analgesia. It can be used as an aid to traditional local anesthesia or for laser analgesia support [100–103].

Some other therapeutic options are not completely proven or verified (e.g., different brands of electrostimulation or electronic anesthesia) or have unpleasant side effects like some topical anesthetics with very high absorption coefficient, i.e., EMLA 5%, cream containing prilocaine and lidocaine (which however give a feeling of numbness, need 15 min of waiting time before they take effect, and are quite distasteful), or potentially harmful (general anesthesia, conscious sedation with drugs, and/or intravenous injection) [104].

Dental lasers are not completely able to replace traditional bur, and it is not always possible to avoid injected anesthesia, but this technology is particularly useful in pediatric dentistry (above all for primary dentition), for phobic patients, and for those who do not like traditional anesthesia due to the feeling of numbness it causes or because they are intolerant to it.

This can explain why the use of this «no shot» modality can be highly appreciated by patients, especially by the youngest.

8.17 How Laser Analgesia Works

The mechanism by which the laser analgesia can take place is not completely known [84, 98, 105–113].

Laser pulses may hamper the possibility for neurotransmission to reach the central nervous system, since the former lasts only microseconds, while it needs milliseconds to be modulated by the brain (gate theory). This overloading of the peripheral and of the central nervous systems can be due to a physiological saturation caused by the laser beam.

It has been assumed also that laser irradiation on pulp C fibers may cause a reduction of the Na-K pump action. Temporary nervous transmission suppression could occur.

Actually, the opinion of researchers converges on the role played by *low-level laser therapy* (LLLT) in preconditioning tissues, and this is likely to be responsible for the onset of the analgesic effect. It is highly plausible that the laser phototherapy action on pain is a combination of several factors [114].

To obtain successful analgesia, it is necessary to apply low-level energy (and power) or, more precisely, it is indispensable low energy density and low power density.

Furthermore, initially it is useful to use low levels of air and water spray which can induce dental sensitivity due to the cooling effect of air and/or water (◘ Fig. 8.13).

◘ **Fig. 8.13** Laser analgesia of tooth #2 keeping the tip at 10 mm from the tooth neck surface with the aid of a spacer (Er,Cr:YSGG Waterlase iPlus laser with wavelength of 2780 nm by Biolase Technology, Irvine, CA, USA). Analgesia settings: MGGG6 sapphire tip diameter 600 µm, length 9 mm, 0.1 and then 0.2 W (energy per pulse of 10 and 20 mJ), 10 Hz, 30 s each (without air/water cooling spray), tip-to-tissue distance 10 mm. Subsequently, the power was increased to 0.5 and then to 1 W (energy per pulse of 33 and 67 mJ), 60 s each, 15 Hz, water 15% (10 ml/min), air 20%, same distance from the tooth neck. Preconditioning of hard tissue before ablation: 2 W, 30 s, 15 Hz, water 50% (20 ml/min) and 80% air, tip-to-tissue distance 1 mm)

8.18 Techniques for Laser Analgesia on Teeth

Two different techniques have been proposed in order to obtain the laser analgesia:

- Rabbit technique (also called *hare technique*): the laser is immediately set on high power levels, able to perform hard tissue ablation, and this is maintained during the whole treatment. At the beginning, however, the beam is kept defocused at 6–10 mm from the tooth. So, the energy density is low, and it takes advantage of the low-level laser therapy. The tip is moved all around the tooth, at its neck level. Then, the tip is gradually brought closer up to 1 mm from the dental surface, and so the ablation effect can start. At this point, if the patient feels some discomfort, it is possible to move aside the tip again. As soon as the beam gets through the enamel and reaches the dentin, the tip is again placed farther away, the laser irradiation becomes defocused (thus reducing the energy density), and cavity preparation is complete.
- Turtle technique (also called *tortoise T.*): the tip is immediately placed at 1 mm from the tooth and kept at this distance for the preparation procedure. Low power is then set in order to obtain pulp analgesia and have a lower risk of discomfort for the patient. Then, the energy is gradually increased up to a sufficient level able to obtain tissue ablation, and this is carried on till enamel ablation is completed. When the dentin is reached, the power is lowered and cavity preparation is completed. This last technique is considered the most reliable to avoid patient's dental sensitivity during the restorative treatment. It is regarded as the most satisfactory, delicate, and effective to obtain dental analgesia [19].

It has been scientifically demonstrated that permanent teeth are more sensitive to pain than deciduous ones and that laser analgesia is easier for the latter [109].

According to Moritz A. (2006) [88], the laser analgesic effect on the tooth should last approximately 15 min, and after its disappearance, no histological alteration of the pulp occurs.

On the contrary, according to *Whitters CJ* et al. [115], the pain threshold after laser analgesia obtained by the means of a Nd:YAG laser returned to baseline approximately after 60 min.

8.19 Protocol for Tooth Analgesia with the Erbium Laser

In order to study erbium laser analgesia, we recently [94] studied a protocol in order to propose a systematic painless restorative treatment of the teeth. We used the Er,Cr:YSGG (2780 nm) laser applying a combination between *rabbit* and modified *turtle technique*.

Before starting cavity preparation, a laser-induced analgesia phase was always performed by initially using very low levels of energy, and then by gradually increasing them, without using any air/water cooling spray.

In this way, the dental pulp had the possibility to adapt to laser irradiation without triggering a mechanism of annoying sensitivity, but gradually performing analgesia. Then, it was possible to obtain a gradual painless ablation of tooth hard tissues.

The analgesia phase was therefore started with power values of 0.1 watt (consequently, the energy had values of only 10 mJ) at a pulse repetition rate of 10 Hz, and afterward these levels were gradually increased to 0.2 watt, then to 0.5 watt with a repetition rate of 15 Hz, and then, finally to 1 watt and to 2 watts with the same pulse repetition rate.

Overall, this stage always lasted 3′30″ (210 s).

The study of laser-induced dental analgesia with regard to cavity preparation was performed by adopting the following sequence:

A. Preliminary pulp test using the electric pulp tester to evaluate dental vitality and to establish the baseline threshold of dental sensitivity.
B. Beginning of the dental analgesia induction phase by using power settings of 0.1 and then 0.2 W (energy per pulse of 10 and 20 mJ) at a pulse repetition rate of 10 Hz, for 30 s each (without using any air/water cooling spray), keeping the tip at 10 mm from the tooth using a spacer. Subsequently, the power was increased to 0.5 and then to 1 W (energy per pulse of 33 and 67 mJ) for 60 s each, with a spray composed by 15% of water (for our laser this means approximately 10 ml/min) and 20% of air, at a pulse repetition rate of 15 Hz, keeping the tip at the same distance from the tooth neck.
C. Preconditioning of hard tissues with 2 W of power for 30 s with a cooling spray of 50% water (approximately 20 ml/min) and 80% air, at 15 Hz of pulse repetition rate, with the tip at approximately 1 mm from the tooth. The laser beam was kept in focus or, if the patient felt discomfort, it was defocused according to sensitivity.
D. Electric pulp test (EPT) performed again to evaluate the presence of analgesia and establish how the threshold value of dental sensitivity had changed.
E. Preconditioning and beginning of enamel ablation with a 3 W power for 30 s (same previous settings as for pulse repetition rate, distance, and cooling spray).
F. Enamel ablation with 4 W of power (same previous settings).
G. Possible enamel ablation with 5–6 W of power (same previous settings).
H. Possible dentin ablation with 3–3.5 W of power (same previous settings).
I. Preparation completion and smear layer removal with a power of 2 watts (same previous settings).
J. Pulp test at the end of the preparation. To assess if the threshold value of dental sensitivity had further changed after the ablative laser irradiation.
K. Pulp test after 15′–20′ from the end of cavity preparation to assess if analgesia was over.

The entire period of laser analgesia induction had an overall duration of 3′30″ (210 s), and it was performed on all patients.

At the end, as specified, cavity preparation started.

To correctly perform laser-induced analgesia in our protocol, we suggest to maintain the tip at a distance of 10 mm from the tooth from the start.

In this way it is possible to obtain a very low energy density from the initial stage (only 6 J/cm^2 with movement) and average power density (1 W/cm^2), thus allowing the pulp to progressively adapt to laser irradiation and achieve analgesia without risking painful or annoying sensations.

With regard to discomfort felt by patients, the factors that seem to have a higher tendency to promote the shift to greater discomfort categories are posterior teeth compared to a superficial one, the time needed for ablation of hard tissues, and the use of laser at high power levels.

One of the most important factors that influenced pain perception was age.

In this study, all patients that felt greater discomfort or pain were in age brackets 20–29, 30–39, and 40–49.

So we think that younger patients could obtain analgesia more easily and quickly as their dental hard tissues are more rich in water and they have wider dentinal tubules. This could facilitate ablation and progression of laser beam effect on pulp nerves.

With regard to older patients, they could be less sensitive to irradiation for the opposite reasons: their dental tissues are more sclerotic and calcified; they have narrow dentinal tubules; and even if they are more difficult to ablate, they protect the pulp more; and they are less influenced by stimuli.

When a restorative treatment with erbium laser is planned, without resorting to any local injected anesthesia, it should be considered that cuspids and incisors may be more sensitive, especially if decays are deep.

For these teeth, the energy can rapidly affect nerve fibers of the pulp because of the limited thickness and cause pain.

Actually, in our research we saw that the opposite was true: premolars and molars were more sensitive than front teeth.

By using our protocol, initially applying very low energy levels and gradual irradiation, we obtained a better and quicker laser analgesia for anterior teeth.

The possible explanation of this is connected to the greater thickness of hard tissues for posterior teeth compared to incisors and cuspids.

It is also our opinion that the depth of the decay is important sensitivity wise, but the time of preparation is more relevant in affecting it.

This is due to the effect of erbium on the dentin. This kind of laser, combined with water, opens the dentinal tubules. The more the laser is used, the more the tubules will be opened, and the higher patient's sensitivity will be.

Besides, if dental hard tissues are not easily laser ablated (e.g., if they include a lower water percentage) and if, for this reason, it is necessary to extend its use for a longer period of time or to increase the energy levels in order to facilitate ablation, then the risk of pain further raises.

One additional element to consider is the fact that laser analgesia could be not completely effective to also achieve periodontal tissues analgesia.

During this research, even if the tooth was completely insensitive to carious hard tissue ablation, we have quite frequently noticed that the patient could feel the discomfort provoked by the positioning of the dental dam clamp, the matrix, or the wedge.

Thanks to the proposed protocol, it was possible to perform a restorative treatment by using the Er,Cr:YSGG (2780 nm) in 24 patients out of 30 (80% of the sample) without resorting to any kind of local anesthesia and without the traditional handpiece and bur.

These patients did not feel any pain (in 57% of cases), or they felt only a very light sensitivity (in 23% of patients). The equipment we used was very likely to produce laser-induced analgesia, which allowed us to remove all the carious tissues and to complete the composite reconstruction without any pain for the patient.

In relevant literature, the comparison between traditional handpiece with bur and erbium laser showed that with the former, the dentist can obtain painless treatment in only 20–50% of patients [116].

The use of Er,Cr:YSGG laser allows to avoid the administration of local anesthesia by injection and to avoid the use of the traditional handpiece and bur. Thus, we can obtain reduced anxiety in patients, something that is frequently associated to dental therapies.

Following these considerations, is it possible to draw some firm conclusions on the strong correlation between anxiety and discomfort?

We believe it is possible to affirm that groups of patients reporting higher levels of anxiety before attending a dental session are the same who felt greater discomfort during therapy. So, it is likely that the anxiety factor contributes to generate a higher subjective evaluation of discomfort.

In adult patients we noticed that the level of anxiety felt during a dental session had more influence on the possibility to obtain complete leaser analgesia; this is probably due to the patient's individual difficulties related to dental care past experiences.

On the other hand, with regard to pediatric patients, if they never had dental experiences in the past, if they were not very anxious by nature, but rather calm and happy, and if they did not have a negative influence from parents and/or relatives, they may be more incline to accept the dental treatment. This will mostly and more easily occur if the dentist will adopt a psychological, positive, delicate, and serene approach.

All of this will be for sure facilitated by adopting the erbium laser if neither needles nor local anesthetics will be used, especially if the operator will avoid noises and vibrations which are typical of the traditional handpiece combined with the bur.

This approach will reinforce and maintain the patient trust toward the dentist.

8.20 The Laser Handpiece and Tips

Most modern erbium lasers are provided with two types of handpiece.

One uses interchangeable tips of various lengths, diameter, and materials.

On the market, there are tips with lengths ranging between 3 and 28 mm. With the shorter tips, it is possible to access small areas within the teeth arch or in difficult spots (i.e., the upper second and third molars, vestibular areas of posterior teeth) or perform treatments when the patient has limited mouth opening (i.e., pedodontic patients). With longer tips and with a small diameter of 200–300 μ, it is possible to perform endodontic and periodontal laser-assisted treatments.

They are made out of quartz or sapphire. Oftentimes, it is possible to differentiate them from one another because of their color, yellowish for the first one and whitish for the second one.

Usually, the most used tips in restorative dentistry are the ones measuring 4–10 mm (▪ Figs. 8.14, 8.15, and 8.16).

▪ **Fig. 8.14** Minimal carious cavity and decalcification in buccal face of tooth #10

Fig. 8.15 Cavity preparation on tooth #10 (Er,Cr:YSGG Waterlase iPlus laser with wavelength of 2780 nm by Biolase Technology, Irvine, CA, USA). Enamel settings: MGGG6 sapphire tip diameter 600 μm, length 9 mm, 3 W, 15 Hz, 200 mJ E per pulse, peak power 3333 W, average power density 492 W/cm^2, peak power density 546.710 W/cm^2, total energy 90 J, pulse width 60 μs, 1 mm tip-to-tissue distance, 50% water (18 ml/min), 80% air. Dentin and smear layer settings: MGGG6 sapphire tip diameter 600 μm, length 9 mm,2 W, 15 Hz, 133 mJ E per pulse, peak power 2222 W, average power density 328 W/cm^2, peak power density 364.473 W/cm^2, total energy 20 J, pulse width 60 μs, 1 mm tip-to-tissue distance, 50% water (20 ml/min), 80% air

Fig. 8.16 End of composite reconstruction of tooth #10 (adhesive system OptiBond FL total-etch adhesive system (Kerr, Orange, CA, USA), composite material Enamel Plus HFO by Micerium, Avegno, Genova, Italy)

The tip-to-tissue working distance should constantly be kept at 0.5–1 mm in order to obtain optimal energy density. In some scientific articles, this operational modality is wrongly defined «in contact» since the operator is working at close proximity with the tooth. Nevertheless, there should never be contact, and the tooth surface should never be touched in order to avoid the creation of enamel-dentinal microfractures and to avoid damages to the delicate laser tips.

This working modality is also called «focused,» even if in reality the laser beam is not convergent, i.e., it is not focused on the target. The laser energy delivered by the tip is in fact immediately diverging with approximately an 8° divergence angle per side.

The reason to keep the tip at 0.5–1 mm is due to the fact that at that distance, energy density (fluence) is optimal, and it is the one that allows a more efficient ablation.

By increasing the distance, fluence will drop dramatically, preventing adequate excisional interaction with tissues.

On the other hand, if the working distance is below 0.5 mm, the operator may run the risk of causing dental damage following contact, and tip deterioration after accidental crash against the cavity surface, with reduced effectiveness of the air/water spray to cool and eliminate residues and a very limited visibility on the working area.

The diameter of tips used for hard tissue ablation usually ranges between 400 and 1000 μ. The smaller the diameter, the smaller the cavity the operator can prepare and save healthy tissues. Tips with larger diameter produce a spot size which will inevitably create a bigger size cavity; thus, it is not possible to do small or very conservative preparations. For minimally invasive dentistry, for example, for a minimal cavity including only occlusal grooves, it is preferable to use a tip with the smallest diameter as possible. By doing so, preparation will be quicker because there will be more energy density since all of the energy will be focused on a smaller surface.

Usually, tips used for this type of therapies are cylindrical with a circular section. However, on the market, there are truncated-cone-shaped tips, with rectangular section, chisel-shaped. Each one of them creates a different beam emission which, in its turn, provides an ablation print producing a different cavity shape.

The second type of handpiece is also called *tipless* because it does not have the previously described tips, but a lens which can also be interchangeable, and it focuses the beam at a distance of about 5–10 mm from the surface. Operators work at a greater distance compared to the previous handpiece. At times in the scientific literature, this type of use is defined as «defocused,» but this is not the correct term. In reality, the beam is focused at a few millimeters (usually 5–7 mm) away from the surface of the handpiece from which the beam is delivered. Such use is defined as «contactless.» This greater distance from the target improves visibility, but it provides a less favorable and uncomfortable perspective in poorly accessible areas such as the upper molars. The reason is that it is more difficult to position at that distance and keep accuracy at 5–10 mm from target. Furthermore, it is very difficult to accurately irradiate a small target since the beam is wider. The target area (spot size) covered by the beam tends to be larger than when the operator works almost in contact; thus, it is very difficult to prepare very small cavities, and, if the hand piece is not kept steady on the ablation target zone, the effect is often dispersed on a wider area, resulting in an unintended widening of the cavity and elimination of healthy tissue. This handpiece, however, is more efficient since it allows the removal of a larger amount of decayed tissue in less time.

8.21 The "Erbium Noise"

All types of handpiece produce a similar and characteristic noise. It is often defined as a «popcorn» type of noise, as it reminds corn popping in the pan. It is completely different from the noise produced by a traditional turbine and by the bur; thus, patients tend not to associate it to the fear for the dentist.

Noise intensity is directly proportional to the employed energy, which creates micro-explosions in the water present in tissues and in the one used for cooling. Also, irradiation frequency impacts noise. The higher the number of pulses, the lower the number of «explosions» heard as they will «merge» with one another and they will sound like one noise. At about 30–40 Hz, the noise is continuous, without interruptions between pops.

8.22 Approach According to Cavity Classification

Depending on the place where the decay lesion is, the removal approach will be different.

8.23 Class I

Occlusal decay on posterior teeth (class I) is obviously easier to treat, but the enamel is quite thick. Thus, it may be necessary, additional time to fully remove this type of lesions, especially in the case when they extend under the occlusal plane and when the decay opening is limited with a lot of healthy tissue covering the entire lesion. In order to avoid extended laser ablation, and to reduce operating times, the operator can also open the decayed enamel grooves by using a small diamond bur and only use laser irradiation later on.

Small-sized cavities are more difficult to treat because they are less accessible. The combination of small high-speed diamond bur and lasers with minimum diameter tips is certainly advantageous.

Usually, ablation starts by placing the tip perpendicular to the tooth surface, by making small, very slow continuous movements and by keeping that position from the beginning of the creation of a small cavity. Later on, the beam should be gradually oriented toward the cavity walls outwardly (up to a maximum of 45° per side) to complete preparation [19].

For larger cavities inside the dentin and with large geometries, it is very difficult to reach each side of the walls. In this case, it could be necessary to eliminate much healthy tissue in order to be able to complete the full decay removal. The use of low-speed burs and manual excavators may allow to remove the residual decayed tissue and avoid the elimination of healthy tissue.

8.24 Class II

Cavities concerning premolar and moral interproximal areas (Black's class II), when they need preparation from the occlusal surface, they normally require more execution time by using the laser rather than the bur because the volume of tissue to be removed is considerable and the enamel wall can be large.

Visibility is often reduced, as well as accessibility. To be able to reach any area concerned with the carious lesion, it is key that the tip is placed inside the cavity that is being created, in order to keep the correct tip-to-distance constant. The most difficult aspect is represented by the difficulty of sufficiently inclining the tip toward the walls to be prepared. It should be reminded, in fact, that the angle formed by the tip vis-à-vis the decayed cavity wall should not exceed 45° otherwise ablation becomes ineffective.

8.25 Classes III and IV

In the case of class III and class IV cavities, accessibility is, on the other hand, much higher; thus no major difficulties are noted. Enamel thickness is limited, and, thus, preparations normally require short times and reduced laser energy, compared to those to be used for posterior teeth.

Laser preparations can also be more conservative than the ones obtained with traditional techniques.

In order to protect nearby teeth and avoid damages to their surfaces, it is advisable to place a cellulose strip interproximally to prevent the laser beam to affect the healthy walls of nearby teeth. It would be better instead not to use metal matrixes for the same purpose as they could reflect the laser beam and thus become a source of potential risk for operator's eye safety.

8.26 Class V

Decayed cavities referred to the cervical area (Black's class V) can be prepared easily and in short times, thanks to the limited thickness of the enamel and to the presence of root cement nearby.

For front teeth, it is also possible to use a straight handpiece instead of the angled one (when the erbium laser manufacturer provides it) to facilitate access to tooth neck decay. With regard to the cervical area of posterior teeth, it is usually easier to use an angled handpiece and 3–4 mm length tips which facilitate access to vestibular or lingual areas, despite the interference of cheeks and/or the tongue (◘ Figs. 8.17, 8.18, 8.19, 8.20, 8.21, and 8.22).

Fig. 8.17 Detail of class V carious lesions of teeth #27–28

Fig. 8.19 Widening of preparation in tooth #27

Fig. 8.18 Ablation of enamel and dentin in tooth #27 (Er,Cr:YSGG Waterlase iPlus laser with wavelength of 2780 nm by Biolase Technology, Irvine, CA, USA). Enamel settings: MGGG6 sapphire tip diameter 600 μm, length 9 mm, 3 W, 15 Hz, 200 mJ E per pulse, peak power 3333 W, average power density 492 W/cm^2, peak power density 546.710 W/cm^2, total energy 90 J, pulse width 60 μs, 1 mm tip-to-tissue distance, 50% water (18 ml/min), 80% air. Dentin and smear layer settings: MGGG6 sapphire tip diameter 600 μm, length 9 mm,2 W, 15 Hz, 133 mJ E per pulse, peak power 2222 W, average power density 328 W/cm^2, peak power density 364.473 W/cm^2, total energy 20 J, pulse width 60 μs, 1 mm tip-to-tissue distance, 50% water (20 ml/min), 80% air

Fig. 8.20 Gingivectomy performed to uncover the healthy margin of the preparation in tooth #27 (Er,Cr:YSGG Waterlase iPlus laser with wavelength of 2780 nm by Biolase Technology, Irvine, CA, USA). Gingivectomy settings: MGGG6 sapphire tip diameter 600 μm, length 9 mm, 2.5 W, 25 Hz, 100 mJ E per pulse, peak power 1667 W, average power density 410 W/cm^2, peak power density 273.355 W/cm^2, total energy 150 J, pulse width 60 μs, in contact, 40% water (16 ml/min), 20% air)

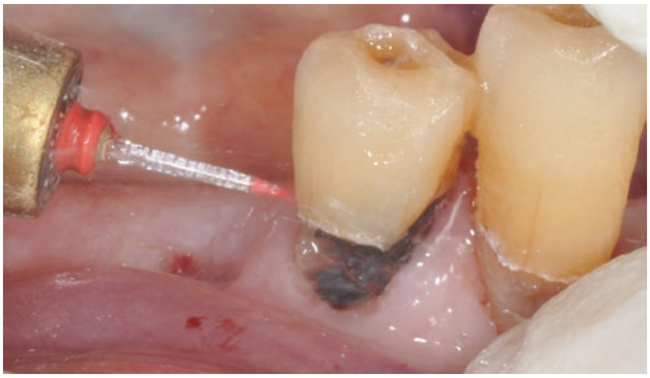

Fig. 8.21 Preparation of cavity in tooth #28 (Er,Cr:YSGG Waterlase iPlus laser with wavelength of 2780 nm by Biolase Technology, Irvine, CA, USA). Enamel settings: MGGG6 sapphire tip diameter 600 μm, length 9 mm, 3 W, 15 Hz, 200 mJ E per pulse, peak power 3333 W, average power density 492 W/cm^2, peak power density 546.710 W/cm^2, total energy 90 J, pulse width 60 μs, 1 mm tip-to-tissue distance, 50% water (18 ml/min), 80% air. Dentin and smear layer settings: MGGG6 sapphire tip diameter 600 μm, length 9 mm,2 W, 15 Hz, 133 mJ E per pulse, peak power 2222 W, average power density 328 W/cm^2, peak power density 364.473 W/cm^2, total energy 20 J, pulse width 60 μs, 1 mm tip-to-tissue distance, 50% water (20 ml/min), 80% air

Fig. 8.22 End of class V composite reconstructions of teeth #27–28 (adhesive system OptiBond FL total-etch adhesive system (Kerr, Orange, CA, USA), composite material Herculite XRV Unidose (Kerr, Orange, CA, USA))

8.27 Interaction with Dental Materials

It is always important to pay attention to dental materials present on nearby teeth.

The erbium laser beam can very easily interact with the amalgam, composites, and dental metal alloys.

Irradiated silver-based amalgam can rapidly absorb energy, increase temperature, and create thermal problems to pulp and periodontium. Should the temperature further increase, amalgam melting may occur with subsequent damages to reconstruction and release of mercury vapor. In case of secondary decays or reoccurring decays under the amalgam filling, it is always necessary to remove the metal reconstruction through traditional methods (by high-speed bur), and only after this operation, carious tissues can be removed by laser.

Interaction with composites occurs very easily when they are irradiated. Their ablation is very easy thanks to the water content. However, the composite is exploded as a result of the interaction with the laser energy; it resolidifies and quickly aggregates around the tip and jeopardizes the integrity of the laser fiber.

Tips altered by resin fragments must be cleaned and polished rapidly to avoid this risk. Tip inspection can be done by wearing amplifying glasses or by using a jeweler's lens with 30 magnifications. Polishing can be done by using rotating disks to polish composites mounted on a low-speed handpiece. It is then possible to gradually move on to rougher disks to the smoother one, and this allows to remove residues, burn marks, correct possible nicks, and polish tips. Such procedure is much easier for quartz tips than for sapphire tips, because the latter are harder. However, polishing may be more complex when there are composite fragments attached to the tip end. These materials, in fact, are difficult to be removed when melted by laser energy, and then they resolidify on it; thus, it is absolutely advisable to avoid resin-based materials ablation during conservative therapy.

In case composite reconstructions need to be redone, it is preferable to remove the old material by diamond bur, and only later on should the laser beam be used to ablate decayed tissues and to extend enamel preparation laterally, to complete dentin excision and condition the final surface before adhesive techniques are performed.

If the tooth near the decayed element has a metal alloy crown, irradiation of the latter can involve thermal interaction quickly leading to temperature increase with potential risks of trauma to the tooth pulp and to the periodontium.

Ceramic crowns, as well as temporary resin crowns, are instead damaged by erbium laser energy. The first type of crowns can be fractured following quick thermal expansion.

If interaction is limited, they undergo scratches or nicks.

The second type of crowns, as one can easily imagine, erodes rapidly as it happens with composite fillings.

Non-precious metal alloys used for removable prosthesis are easily interested by temperature increase, while pink resins and artificial teeth can be damaged.

For all of these reasons, it is advisable to pay special attention to all surrounding dental materials during the entire conservative therapy.

8.28 Clinical Considerations

Clinical considerations for laser-assisted conservative dentistry are as follows:

- At the end of carious cavity preparation, eliminate unsupported enamel prisms by using manual instruments (enamel cutters, excavators) and/or high- or low-speed handpiece fitted with diamond fine burs or rubber tips to bevel cavity margins. Alternative to this process, it is possible to use the erbium laser to bevel cavity margins. It is advisable to set limited energy values (40–80 mJ) and frequency of about 25–50 Hz.

- Perform acid etching by using orthophosphoric acid at 34–38% to optimize and make the treated surface uniform to regularize the areas affected by the erbium laser beam.
- Use an adequate adhesive system that takes patient's characteristics into account, such as age, teeth conditions (deciduous or permanent), and decay depth, if the tooth has been subjected or not to the endodontic therapy. For superficial cavities, permanent teeth, and teeth treated with root canal therapy, it is advisable to use the *etch-and-rinse* adhesive system. In the other cases, it would be preferable to use a *self-etch* system, in particular if the cavity is deep and if the patient is very young (the same applies to permanent teeth).
- For deep cavities, it may be advisable to use glass ionomer cement or a flowable composite as liner on the cavity floor, in close proximity of the pulp, in order to obtain good protection of the pulp and of deep dentin, and to position in such area a low-elasticity material and limited polymerization shrinkage; these characteristics facilitate optimal reconstruction adaptation to the cavity internal surface.
- Use a photopolymerization lamp with controlled light irradiation (i.e., soft start or pulse delay technique) such to limit polymerization shrinkage of composites and evenly reach all stratified areas.
- Always use an incremental technique to stratify the composite, in order to have max 1–2 mm layers of material and compensate for and minimize its polymerization shrinkage.
- Use low polymerization shrinkage composite resins for reconstruction (i.e., silane-based composites, even if their clinical use should still be further studied and validated).

8.29 Erbium Laser in Reconstruction with Post in Endodontically Treated Teeth

Teeth subjected to endodontic treatments can benefit from the erbium laser use during composite reconstruction performed in combination with a post.

Thanks to irradiation, both canal walls following endodontic treatment and the post can be optimized for the adhesive process.

Most modern posts are made up of carbon, quartz, silica, or glass fibers, embedded in an epoxy matrix or in a methacrylic resin. They have an elasticity module similar to that of dentin, so that under mastication, the material behaves similarly to tooth tissues and forces are discharged in an equivalent way. By combining this property to the possibility of obtaining an adhesive bond among the various materials (root and crown dentin, adhesive system, fiber post, and core material in composite for cementing and reconstruction), it is possible to reduce the risk of fracture [117, 118].

These posts have high biocompatibility, they are easy to use, they have high mechanical resistance and good corrosion resistance, they are easy to be removed, and they have a very high appearance value (for quartz and glass posts).

Post retention by the root depends on the chemical interaction and micro-mechanical strength among post-, dentin-, and resin-based cement. Should there be insufficient bonds between resin and dentin or at interface level between composite and post, restorative rehabilitation will fail, in association with the partial or total detachment of the reconstruction and of the post embedded in it.

The bond strength is influenced by the degree of hydration/dehydration of the inter-canal dentin wall. If the inside of the canal is too dehydrated, hydrophile monomers of the adhesive system will not be able to penetrate dentinal tubules resulting in a lack of hybrid layer. On the contrary, if the water content is excessive, monomers will be excessively diluted, and they will not play their action.

Other factors that contribute to determine a higher or lower retention strength between post and root are represented by physical property of the composite cement, unfavorable canal configuration (accentuated curvature, root with very thin walls not allowing a wider preparation) or due to insufficient canal length which does not allow the positioning of a sufficiently long retaining post, from adverse effects of canal-sealing cements which, by containing eugenol, they combat resin polymerization used for cementing, and due to anatomic or histological characteristics of dental tissues (i.e., number of tubules at the different levels inside the canal) [119].

The post fiber polymeric matrix is highly cross-linked; thus, bonding phenomena with composite monomers do not easily occur. The bond between the reconstruction composite and the post occurs only partially, and the resin acts as a bond with glass or quartz fibers.

To improve the odds of obtaining such link, different types of post and canal wall pretreatments have been proposed. For example, several authors frequently proposed the roughening of post surfaces in view of increasing retention. However, this exposes glass or quartz fibers, and it may give rise to their weakening.

Sand blasting with A_2O_3 powders in 50 μ particles or the use of hydrofluoric acid must be performed with extreme attention to avoid a too aggressive alteration of fibers. For quartz posts, it has been underlined [120, 121] that it would be useful to use the HF acid at a concentration below 9%. In such a way, higher tensile strength is obtained. However, the same treatment can be risky for glass fiber posts because it would induce corrosion.

Some solvents could increase the adhesion strength between quartz or glass fiber posts and the resin core material. In particular, they have been tested with hydrogen peroxide ($H_2O_{2)}$ at 24% for 1 min [122, 123] and dichloromethane (CH_2Cl_2) for 1 min [124].

Both solutions showed promising results but they should still be tested on larger samples.

Erbium laser, besides its decontaminating effect, allows to obtain a smear layer-free surface and a micro-rough texture which can facilitate retention. Following post space preparation, canal wall cleaning is a critical procedure, however indispensable, because there is a lot of smear layer inside the canal, as well as gutta-percha residues and endodontic cement on dentinal walls. All of this represents a contamination that may negatively affect adhesive procedures.

Intratubular moisture and residues of irrigation liquids inside the tubules can furthermore complicate or impair adhesion process steps.

The erbium laser used to provide thorough cleaning and decontamination of the endodontic space allows an extremely accurate cleaning of the dentinal surface and the elimination of the smear layer, but, on the other hand, it is advisable to avoid its excessive use since it may induce dentin dehydration.

It is very important to use limited energy values (from 100 to 125 mJ) and frequency of 10–20 Hz in order not to negatively impact the dental surface and not to create microstructural damages to the dentin and to its hybrid layer [123].

The main difficulty in obtaining efficient laser conditioning on canal walls is represented by the fact that the tips inside the canal irradiate toward the apex with a divergence of 8° per side; thus, the beam reaches dentinal walls with a very marked inclination and that, thus, does not interact much with the surface. For this reason, it is advisable to avoid excessive irradiation and excessively high parameters, since they could damage hard dentinal tissues and their organic portion.

The same parameters mentioned above can be used on the post surface in order to facilitate the formation of microroughness which may have a retention effect on the resin core material and increase post resistance and reconstruction.

8.30 The Use of the Dental Rubber Dam

Just like for all conservative dental procedures, laser-assisted procedures as well must be done with dental dam in place, in order to avoid contamination in the operating area. However, its positioning can also be done right before the preparation of decayed cavities, but after the step in which actual laser analgesia is attempted. The absence of the dental dam allows better irradiation in the tooth cervical area at the level of the dental neck and of the gum surrounding the tooth. Only after formal analgesia, it will be possible to place the dam in place and proceed with cavity preparation by removing carious tissues. In this way, mild analgesia will be achieved in soft periodontal tissues as well, allowing the positioning of the hook, the matrix, and the wedge, that will be perceived by the patient with less or no discomfort at all.

8.31 The Use of the CO_2 Laser with Hard Dental Tissues

The carbon dioxide laser (CO_2 10.6 μm) has been extensively used in the last 40 years for oral surgery.

Its continuous wave (CW) and complimentary gated mode allow an efficient and quick vaporization and ablation of soft tissues, also obtaining a very good hemostasis.

Early studies using a CW 10.600 nm CO_2 reported extensive cracking and charring of enamel, dentin, and bone [125, 126].

During the last 10 years, researchers have modified the native 10.6 μm CO_2 laser transforming it into a pulsed laser.

Now this laser has been changed thanks to the replacement of the normal $^{12}C^{16}O_2$ with an isotopic $^{12}C^{18}O_2$ and emits at 9.3–9.6 μm wavelength which is the peak of absorption for the molecule of phosphate in hydroxyapatite [127]. The absorption is also high in water and proteins (collagen).

This is particularly important because in this case enamel absorption is 5–6 times higher at 9.3–9.6 μm than at the more commonly used 10.6 μm wavelength and it allows more efficient heating and ablation of dental hard tissue [128].

Transverse excited atmospheric pressure (TEA) and radio frequency excited (RF) 3D computer-controlled programmable scanning systems are now on the market available from several manufacturers and seem even more versatile and efficient when compared to erbium family lasers [125, 126].

In fact, with them, it is possible to perform a wide range of procedures. Today, it is also feasible to modify the pulse duration of new carbon dioxide lasers in order to obtain an efficient removal of dental hard tissues (carious lesion ablation, caries prevention, removal of composite reconstructions) and bone, without losing the surgical effect on soft tissues [129] (▣ Fig. 8.1).

The most important feature regarding modern carbon dioxide devices is that they can be operated at high pulse repetition rates in the order of KHz, and this allows a very practical removal rate of hard tissues and an incomparable ability of gum and mucosa cutting [128].

The erbium lasers presently used for hard tissue ablation operate most efficiently at very low repetition rates (10–25 Hz). Therefore, in order to achieve higher cutting rate, erbium lasers must deliver a larger amount of energy per pulse, in the range of 100–500 mJ.

CO_2 lasers can be operated with very low single-pulse energies (in the order of μJ up to mJ) and fluence, while frequency can be increased for higher cutting rates [130].

The laser beam can also be scanned to minimize heat accumulation in one area [125].

The wavelength of 9300–9600 nm is coincident with the strongest absorption of dental hard tissues due to phosphate ions in hydroxyapatite. Therefore, the energy necessary for ablation of tooth hard tissues is lower at these wavelengths versus others, and this allows a reduced accumulation of heat in the tooth. Moreover, due to this very high absorption, the penetration is limited to under 1–2 μm.

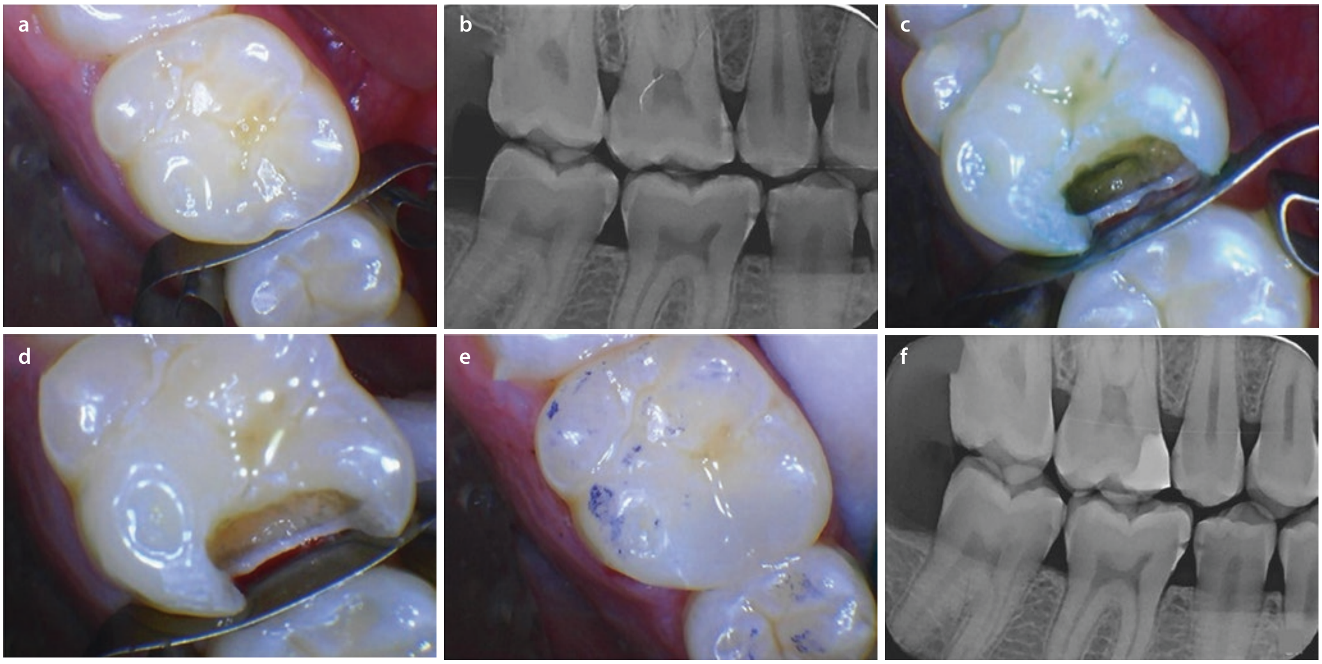

Fig. 8.23 Carious tissue removal in tooth #3 MO using Solea CO_2 9.3 µm laser (Convergent Dental, Natick, MA, USA). Image key: **a** preoperative occlusal view of the upper right molar with a carious lesion on the mesial surface. **b** Preoperative radiograph. **c** A photo of the partially completed carious lesion excavation. The 9300 nm laser with a 1.25 mm spot size was used with a cutting speed between 20% and 60%. Caries indicating solution was used to verify the progress of the preparation. Subsequently the laser was used with a 1.0 mm spot size at 20–40% cutting speed. **d** Photo of the completed preparation. **e** Immediate postoperative view of the restoration in place. **f** Postoperative radiograph showing the competed restoration. The entire procedure was performed without injected anesthesia using the «hard and soft tissue» setting and 100% mist. Caries indicator was used once more before restoring the tooth. The total laser time was 12 min (Procedure by Dr. Josh Weintraub)

With erbium lasers, the shortest pulse width is 50–60 µs, while the CO_2 allows to efficiently ablate enamel and dentin with laser pulses of 10–15 µs [127, 129], so it is possible to obtain high peak power values with lower energy levels, and this can be less aggressive and has a lower possibility to damage the dental structure [128, 131].

According to Staninec M. et al. [125], the thermal relaxation time of the energy deposited in enamel at these wavelengths is on the order of 1–2 µs for enamel and 5.5 µs for dentin [130], so the use of a laser with pulses of 10–20 µs width reduces the threshold for plasma shielding in the plume of ablated material, which would shield the surface and reduce the efficiency of irradiation, allowing the ablation of enamel and dentin at rates of 10–20 µm per pulse and 20–40 µm per pulse, respectively [125, 127].

The use of longer CO_2 laser pulses has the advantage of raising the plasma-shielding threshold allowing higher ablation rates per pulse; however, the longer pulses are more likely to produce a larger zone of peripheral thermal damage. The practitioner should remember that, although ablation rates are higher for longer pulses, the peripheral thermal damage caused by these longer pulses may be too extensive for practical use. Such thermal damage may result in thermal stress cracking, accumulation of non-apatitic calcium phosphate (CaP) phases on the surface, and excessive damage to the collagen matrix [125, 132], so it is advisable to limit the length of laser pulses (Figs. 8.23 and 8.24).

8.32 Resistance to Acid

Another important advantage of CO_2 use is the chemical and structural modification of enamel surface obtainable during irradiation [128].

This laser irradiation vaporizes water and protein and changes the chemical composition of the remaining mineral content of enamel and dentin, thus decreasing the solubility to acids with an enhanced resistance to secondary caries [126].

This allows to increase the acid resistance and consequently to reduce the incidence of carious lesions [133–136].

The occlusal pits and fissures are the areas of the tooth in which dental caries are more frequent. The thermal modifications of these surfaces due to CO_2 laser are desirable to transform them and obtain a greater resistance to acid dissolution.

One possible therapeutical approach is to irradiate the grooves of occlusal surfaces with this laser prior to placing sealants to further enhance the resistance to decay.

Should the practitioner need to remove a sealant due to its failure, the same laser can be used for this purpose [137].

It is also important to underline that irradiation with this wavelength reduces the sensibility of dental tissues to acid etching.

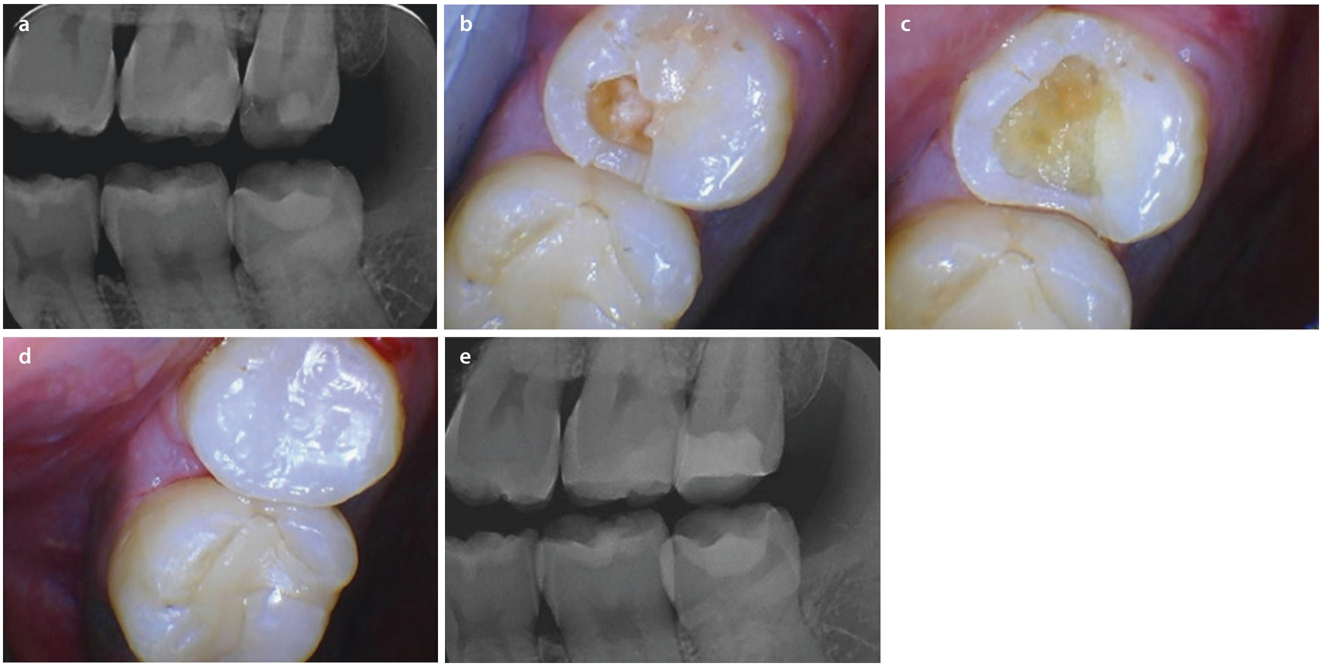

Fig. 8.24 Deep cavity preparation removal in tooth #16 MOB using Solea CO_2 9.3 µm laser (Convergent Dental, Natick, MA, USA). Image key: **a** preoperative bitewing radiograph tooth #16 (UL8). **b** Preoperative view of carious lesion. **c** Completed cavity preparation. The 9300 nm laser with a 1.25 mm spot size was used with a cutting speed between 40% and 60%. Then, for decay removal in dentin, the 1.00 mm spot size was used with cutting speed between 30 and 40%. Finally, the 1.00 and 0.25 mm spot sizes were used with 50% mist. **d** Photo of the completed preparation. **e** Postoperative radiograph showing the competed restoration. The entire procedure was performed without local anesthesia using the «hard and soft tissue» setting and 100% mist. The total laser time was 12 min (Procedure by Dr. Josh Weintraub)

8.33 Pulpal Temperature Considerations

Enamel, dentin, and bone can be rapidly removed thanks to CO_2 laser without peripheral thermal damage by mechanically scanning the laser beam and also with the aid of cooling water spray [128].

If compared to a high-speed traditional handpiece, this laser allows to avoid excessive peripheral, thermal, or mechanical damage [131], provided the use of enough water cooling is guaranteed, otherwise some desiccation of tissues might occur.

Thermocouple measurements showed an increase in temperature of 3.3°± 1.4 °C without water cooling versus 1.7°± 1.6 °C with water cooling [125, 127].

Even though the tooth temperature rise was less than 5 °C without water cooling during an irradiation at 50 Hz, it is still necessary to use a water spray to produce the desired effect. This is advisable for the possible formation of non-apatitic calcium phosphate phases that are produced without a proper cooling due to excessive overheating of the mineral phase [125].

One disadvantage related to the use of this powerful laser is the formation of highly conical and deep ablation craters created when the irradiation is performed in the same spot by repeated laser pulses. This is also at the base of stalling phenomenon (cessation of ablation after penetration of 2–3 mm) and of excessive heat accumulation.

To avoid it and obtain a more efficient ablation, it is necessary to use small spot sizes (< 0.3 mm), and the laser should be scanned in two dimensions to expose a new area for each pulse [125, 131].

Scanning and positioning of the beam is now feasible due to recent advances in compact high-speed scanning technology such as the miniature galvanometer «galvo»-based scanners [131, 138].

8.34 Composite Removal

Lasers can also be used for selective ablation of composite when replacing failed restorations or removing residual composite after debonding of orthodontic brackets [137].

The composite material can be easily and quickly removed without damage of dental surface, without any charring and limiting the removal of sound enamel (Fig. 8.2). It can be effortlessly obtained at a reduced fluence, cleaning the operative area with water spray, so to avoid discoloration and thermal damage [137].

For this purpose, the pulse duration should be comprised between 10 and 20 µs, and the pulse repetition rate should be 200 Hz.

The area of localized damage to enamel can reach a depth of less than 10 µm with a fluence of 3.2 J/cm^2 [136] or below 20 µm with a fluence in the range 5–10 J/cm^2 [137]. If the energy density exceeds the value of 4–5 J/cm^2, there will be a greater removal of enamel, but this is considered unacceptable on buccal tooth surface [136].

This very limited amount of healthy enamel loss, due to the high degree of selectivity and minimal deposition of heat in the tooth, appears to be less than what it is obtainable with the conventional means of removal using dental low-speed and/or high-speed handpiece.

Moreover, measurements of the enamel loss during a routine brush and prophylaxis reported average values ranging from 6 to 17 μm, depending on the material employed.

On the contrary, the Er:YAG and Er,Cr:YSGG lasers, which are usually employed for this purpose, adopt higher single-pulse energy levels (100–500 mJ per pulse) and greater energy densities (20–100 J/cm^2) to remove hard tissues, orthodontic cements, and resin materials.

These pulses can remove up to 50 μm of enamel and up to 200 μm of dentin each, possibly causing a severe damage to the underlying tooth structure.

The temperature rise at the pulp level during composite ablation has an average maximum value of 1.9°± 1.5 °C [136], below the critical limit of 5.5 °C [137] that is considered dangerous for tooth vitality according to Zach and Cohen [139].

In conclusion, dental hard tissues can be rapidly ablated with a mechanically scanned computer-guided CO_2 laser at high pulse repetition rates without excessive heat accumulation in the tooth or peripheral thermal damage that produce no significant reduction in the tissue's mechanical strength or a major reduction of adhesive strength to restorative material [127, 130].

Conclusion

For as long as laser photonic technology has been available within dentistry, there has been demand for laser-assisted hard dental and osseous tissue management. Notwithstanding the early adoption of the CO_2 soft tissue laser to offer bone ablation, much of the progress in developing clinically appropriate therapy occurred only with the development of the mid-infrared wavelengths, commonly and collectively termed the «erbium family.» Latterly, the emergence of a suitably tailored emission of 9300 nm CO_2 laser has broadened the options available to the restorative dentist and oral surgeon.

Through this chapter, the multiple variants in energy manipulation necessary to provide sufficient power to ablate target hard oral tissue have been explored, and their underlying association with the need to cause as little collateral damage to adjacent nontarget tissue, especially the vital pulp, is determined. Associated concepts of pain management through laser use have been evaluated together with appropriate techniques to allow the novice clinician to adopt these valuable added benefits.

With a thorough understanding of the concepts of laser-tissue interaction, the biophysics involved, and appreciation of the laser instruments available, the restorative clinician may easily and predictably incorporate laser photonic technology as a prime treatment adjunctive in the delivery of dental care.

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