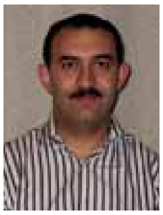

Munther Sulieman

An Overview of the Use of Lasers in General Dental Practice: 1. Laser Physics and Tissue Interactions

Abstract: High tech dentistry now involves the routine use of lasers in general dental practice for various procedures once thought only possible with the conventional dental drill or scalpel.

In 1990, the first dental laser, the dLase 300 (American Dental Lasers, Corpus Christi, TX 78405 USA), was introduced to the profession. There are now many different types of laser used in dentistry using a variety of wavelengths. Each laser wavelength is absorbed differently by soft and hard tissues and the efficiency of the laser has been determined by the ability of the tissue to absorb or reflect that wavelength. This and the following article hope to give a broad overview of dental lasers and their clinical uses. This article gives an overview of the relevant laser physics and highlights the laser-tissue interactions.

Clinical Relevance: The number of laser users is increasing within the profession but there is very little undergraduate or postgraduate training available. It is hoped that the reader will be able to gain the core knowledge essential in understanding lasers and their uses in dentistry.

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Shortly after Maiman's discovery of lasers in 1960,[1] research into the use of lasers in dentistry began with initial experimentation with pulsed ruby lasers, leading to the conclusion that the energies required to cut enamel would endanger the pulp of the tooth. Further work was carried out in the 1970s with the carbon dioxide laser wavelength for 'heat treating' tooth surfaces, so that they become less permeable to acidic fluids and, possibly, more resistant to caries formation.[2] The strong absorption of this wavelength by water in the oral cavity meant that it was finding use in cutting, vaporization and coagulation of the gingivae and other soft tissues. However, it was not until 1990 that a pulsed Nd:YAG (Neodymium: Yttrium Aluminium Garnet) laser, specifically dedicated for dental use, was introduced for some hard as well as soft tissue procedures.

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Since the introduction of this dental laser, many different types of lasers have been evaluated in dentistry using various wavelengths. Each operating wavelength is absorbed differently by soft and hard tissues and the efficiency of the laser is determined by the ability of the tissue to absorb or reflect that wavelength.

Lasers of different wavelength are currently used in nearly all dental specialties alongside conventional techniques or as a replacement for them.

The word 'LASER' is an acronym for Light Amplification by Stimulated Emission of Radiation, with the first laser discovered by Maiman of the Hughes Aircraft Corporation in 1960.[1] However, the development of the theory of stimulated emission dates back to 1916 with the work of Albert Einstein[3] who used the concept of quantum theory of physics and the addition of further quanta of energy to explain stimulated emission.

Light Amplification by Stimulated Emission Radiation

Light is a form of electromagnetic energy that travels in waves at a constant speed, with the photon being the basic unit of this radiant energy. A wave of photons can be defined by

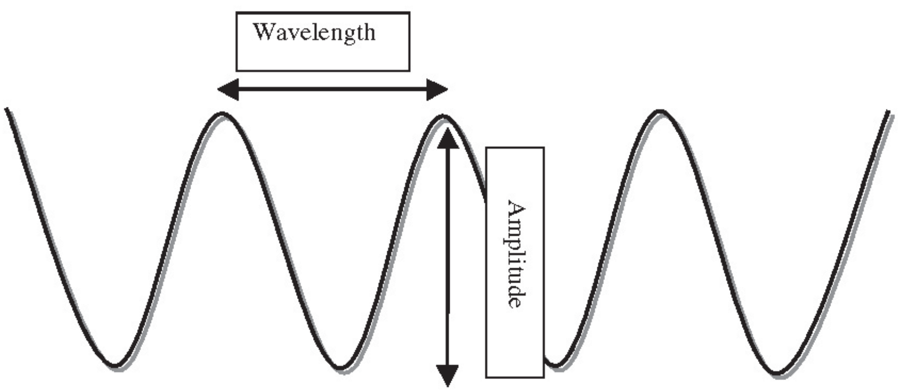

Figure 1. A wave of photons (light energy) can be defined both by amplitude and wavelength.

amplitude (which is the total height of the wave oscillation from the top of the peak to the bottom) and wavelength (which is the distance between any two corresponding points on the wave). The wavelength of laser energy is important in terms of both how this energy is delivered to the operative site and its effect on the tissue.

Ordinary white light seen by the human eye is the sum of the many colours of the visible spectrum; it is usually diffuse, non-focused, with many different amplitudes and wavelengths, whereas light produced by a laser has opposite properties, being monochromatic (one colour) and is very finely focused. In addition to this, the laser beam is collimated, meaning there is a constant beam size and shape out of the laser similar to X-radiation. It is also coherent, a property unique to lasers, in that there are physically identical light waves all in phase with one another with identical amplitude. Figure 1 shows the different parameters of a wave of light energy: wavelength and amplitude.

On encountering matter, light can either be reflected or absorbed where the photons of energy are not destroyed but rather used to increase the energy of the absorbing atom or molecule.

Spontaneous emission

An atom can absorb a photon of light, which ceases to exist, and an electron (e^-) within that atom jumps up to a higher energy level. This atom is now in an excited or pumped state relative to its resting or ground state. However, in the excited or pumped state the atom is unstable and undergoes spontaneous decay back to its resting or ground state, releasing the stored energy in the form of an emitted photon (Figure 2a). This process is called 'spontaneous emission' and the interval between absorption and re-emission is very short. In any given atom, only certain energy levels are possible. When a photon is absorbed, the atom jumps to one of the allowable energy levels. That is, each type of atom can only absorb photons of exactly the right energy or wavelength. Hence, each species of atom has a unique absorption spectrum.

Stimulated emission and light amplification

While an atom is in its excited or pumped state, a photon of energy of the right wavelength enters its electromagnetic field and causes the decay of the excited e^- to the lower energy state before this process occurs spontaneously. This is accompanied by the release of the stored energy in the form of a second photon. The first photon is not absorbed but continues on to encounter other excited atoms. The net result of this process of 'stimulated emission' is two photons of identical wavelength travelling in the same direction at the same time which are said to oscillate in phase (Figure 2b). In a collection of atoms, where there are more atoms in an excited than resting state, there is said to be a population inversion. This is a necessary requirement for production of a laser light.

Spontaneous emission of a photon from one atom will stimulate the release of a second photon from a second atom. These two photons will similarly go

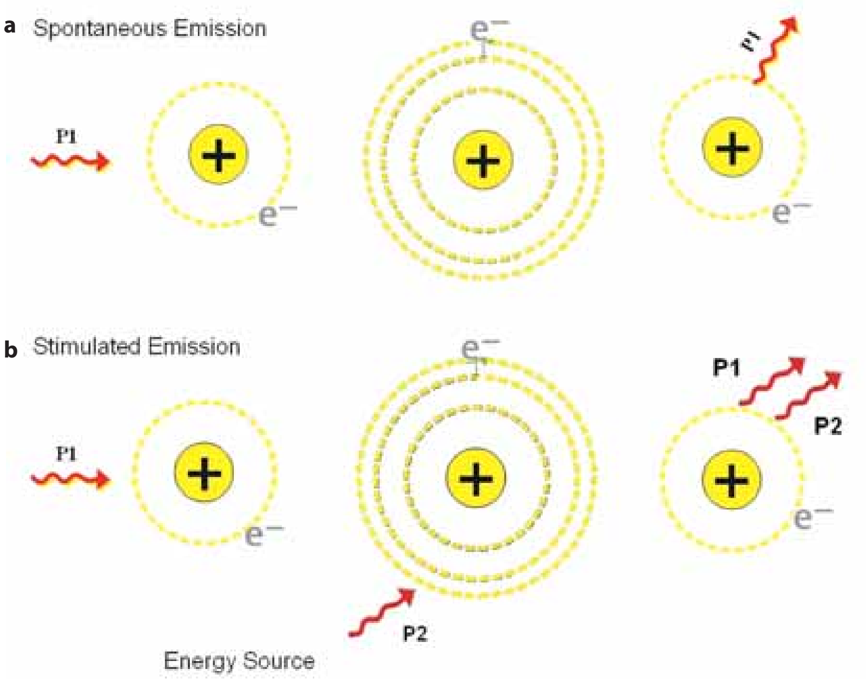

Figure 2. The concept of **(a)** 'Spontaneous' and **(b)** 'Stimulated' emission of photons of light energy (P1 and P2) on encountering an atom.

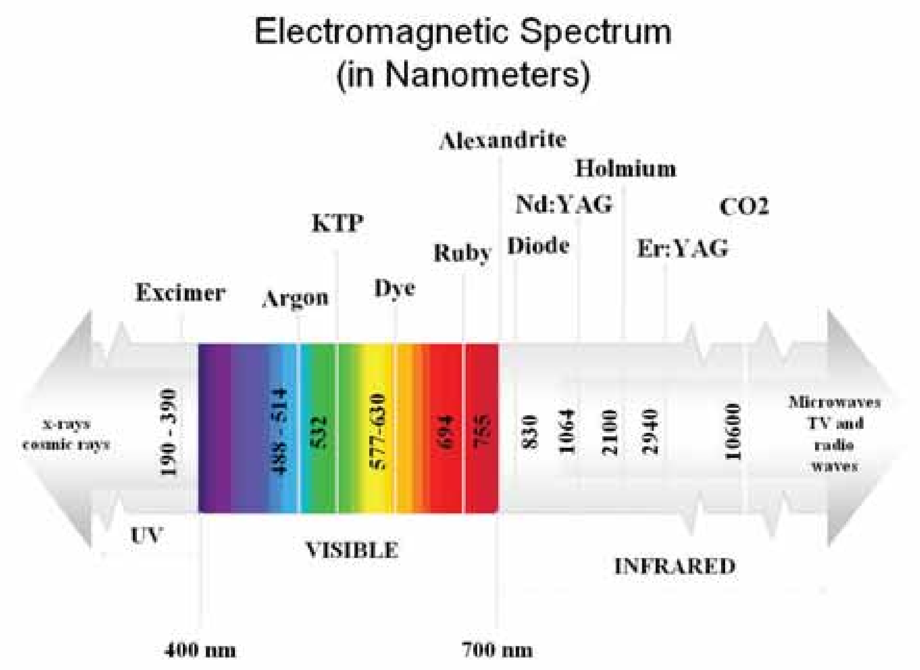

Figure 3. The electromagnetic spectrum.

on to stimulate the release of a further two more photons; these four then yield eight photons; eight yields 16, and so on, producing a brief intense flash of monochromatic coherent light.

The resultant light produced from this photon chain reaction produces the coherent light characteristic of a laser.

Dental lasers

Lasers used in dentistry have emission wavelengths that range from 0.5 to 10.6 microns (500 nm to 10600 nm). They are therefore in either the visible or the invisible infra-red, non-ionizing portion of the electromagnetic spectrum (Figure 3). Hence, they emit either a visible wavelength of light or an invisible infrared or UV light.

A laser consists of a laser medium in a resonant cavity with a power supply and a cooling system with some form of control to the unit. Lasers are named after the chemical elements, molecules or compounds that comprise the core, or active medium, that is stimulated. This active medium can be a container of gas, as in the case of a carbon dioxide laser, a solid crystal rod such as an erbium:YAG laser, or a solid state electronic device in the case of a diode.

In order to house the collection of excited atoms and amplify the process of stimulated emission of photons, the laser medium is located within a resonant optical cavity, which typically consists of two mirrors some distance apart aligned so that their reflecting surfaces face each other (Figure 4). Photons bounce back and forth off these mirrors and re-enter the medium to stimulate the release of more photons. If some form of energy is provided to pump and keep atoms in an excited state continuously, then the population inversion can be maintained and generate high-intensity light. This light, travelling in a parallel direction perpendicular to the mirrors, will bounce back and forth many times across the laser medium, increasing in power or being amplified many times before it is powerful enough to be useful.[2] One of the reflective mirrors is only partially reflective to incident light on its surface, 80% being a common example, letting the other 20% 'leak out' at one end of the resonant cavity. The laser light that leaks out emerges as a monochromatic and directional beam of energy.

Only part of the power pumped into the laser medium is converted into laser light. Some of the input power is converted into heat, raising the temperature of the laser medium. That is, any light energy that does not pass perpendicularly between the two reflective mirrors will go astray and be lost as heat, which has to be removed from the resonant cavity. The heat is removed by a cooling system, which maintains the temperature of the laser medium at an optimum level consistent with maximum lasing efficiency. The laser usually has a controlling system which is a microcomputer/microprocessor located inside the unit with a control panel from which the operator dictates the laser power required and other output parameters.

Carbon dioxide (CO_2) and argon are active gas mediums used in dentistry at present. The remainder that are currently available are either solid state semiconductors made with metals such as gallium, aluminum and arsenide, or solid rods of garnet crystal made generally from yttrium and aluminum that are doped or impregnated with the elements of chromium, neodymium, holmium or erbium. The ends of these laser rods are typically polished very flat and smooth, to allow laser light to pass back and forth through the rod without optical distortion.

A carbon dioxide laser uses a mixture of CO_2, nitrogen and helium gas, but only the CO_2 molecules undergo stimulated emission and generate the laser light. Solid-state laser rods are usually excited or pumped into stimulated emission and lasing optically using white light from a flash lamp or arc lamp, or monochromatic light from another laser. To pump the active gas laser medium, an electrical current or radio frequency is passed through the gas mixture to create an electrical discharge in the medium. Semiconductor diode lasers are a special kind of solid-state laser. Although they are made of a solid-state material, they are not pumped or excited optically but by passing an electric current. They are fabricated out of semiconductor crystals, like LEDs used in electronics and emit light when an electric current passes through them. However, unlike LEDs, laser light is generated in a beam that is much more directional and monochromatic.

Emission modes and laser delivery

Lasers utilize different delivery systems, depending on the wavelength of

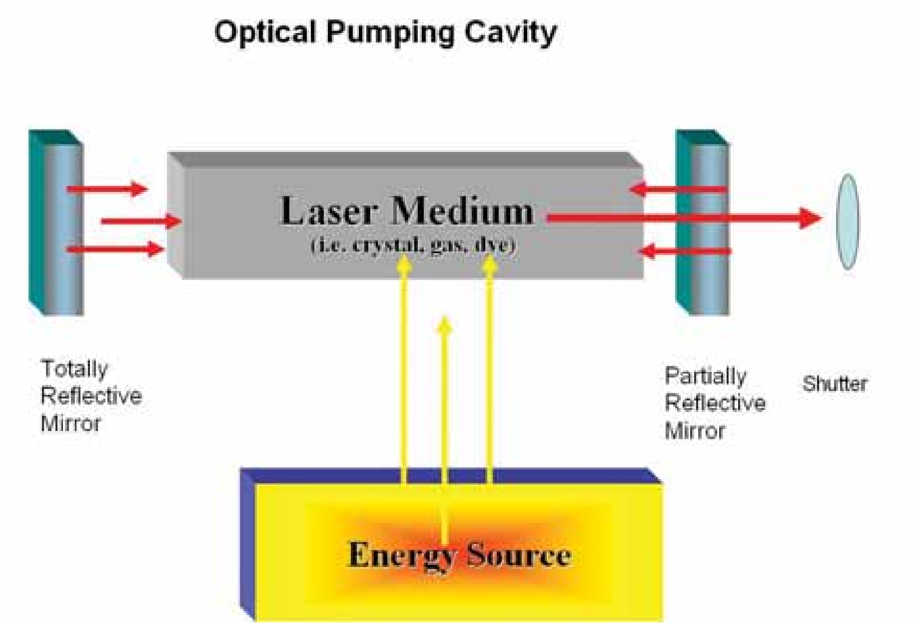

Figure 4. Components of a laser device.

the laser and the tissue access required at the terminal target tissue. These include:

- Articulated arms: these have joints that allow the arm to bend and be configured as necessary to bring the end to the target tissue. The articulated arm is made of tubes connected together at the joints where a mirror reflects the laser beam into the centre of the next tube without touching the inner surface of the arm's inner tubes. At the terminal end, the beam is concentrated onto the tissue using a focusing lens attached to the end of the arm. Articulated arms tend to be bulky, with large outer diameters, and are easily misaligned in use so that the laser beam loses energy in passage through the arm. In addition, aiming beams used to indicate the exact focal point of the laser beam are also delivered through the arm and misalignment of this can have serious implications on surgical control.
- Hollow waveguide: this is a flexible hollow tube that has an interior mirror finish. The laser energy is reflected along this tube and exits through a handpiece, with the beam striking the tissue in a non-contact fashion, without directly touching it. They are much thinner than articulated arms and the need for a series of mirrors is eliminated, but they are also quite short in length and sharp bends must be avoided during use to avoid excessive energy loss. The waveguides are cooled with a flow of gas through the hollow core.
- Glass fibre optic cable: this is more flexible than a waveguide, usually smaller in diameter, with sizes ranging from 200 to 600 microns. The quartz optical fibre is encased in a resilient sheath; it can be somewhat fragile and cannot be bent into a sharp angle. The fibre fits snugly into a handpiece with either the bare end protruding or, in some cases, with an attached glass-like tip. This fibre system can be used in either contact or non-contact mode; however, the majority of the time it is used in light contact fashion, directly touching the surgical site. Like the waveguides, optical fibres typically maintain a good overlap of aiming laser beams at the tissue surface.

The wavelength of the laser determines the best mode of delivery as fibre-optic cables are not efficient at transmitting all wavelengths. Wavelengths of 300 nm to 2400 nm are efficiently transmitted by optic cables, meaning that most of the energy put in comes out at the terminal end of the cable, whereas wavelengths above 2400 nm and below 300 nm are absorbed by the quartz fibre and the laser energy is merely converted to heat. Hence carbon dioxide laser energy at a wavelength of 10,600 nm is absorbed after only a few millimetres of travelling through an optic cable.

Dental lasers can be used either in contact or non-contact mode. Contact mode provides easy access to otherwise difficult to reach areas of tissue. The fibre tip can easily be inserted down a root canal to sterilize the canal, or into a periodontal pocket to remove small amounts of granulation tissue. In non-contact mode, the beam is aimed at the target at some distance away from it, which can be useful for following various tissue contours, but there is loss of tactile feedback which necessitates that the operator pays close attention to the tissue interaction with the laser energy. Dental lasers that operate in the invisible end of the spectrum are equipped with a separate aiming beam, which can either be laser or conventional light. The aiming beam is delivered along the fibre or waveguide in a separate channel and shows the operator the exact spot where the laser energy will be focused.

In either modality, the beam is focused by lenses within the laser itself. With the hollow waveguide, there will be a precise spot at the focal point where the energy is greatest, and that spot should be used for incisional and excisional surgery. For the optic fibre, the focal point is at or near the tip of the fibre, which again has maximum energy. When the handpiece is moved away from the tissue and away from the focal point, the beam is defocused, and becomes more divergent. At a small divergent distance, the beam can cover a wider area, which would be useful in achieving haemostasis, for example. At a greater distance away, the beam loses its energy and dissipates away.

Lasers emit light energy in three basic modes:

- Continuous wave: the beam is emitted continuously at one power level for the length of time the operator depresses the footswitch.
- Gated-pulse mode: the laser energy is switched on and off like a strobe light by opening and closing a mechanical shutter in front of the beam path of a continuous wave every few milliseconds.
- Pulsed mode: often termed free-running pulsed mode, it is unique in that very large energies of laser light are emitted for an extremely short time, of a few microseconds usually, followed by a relatively long time in which the laser is off. This process is computer-controlled, not mechanical as in

the case of gated-pulse mode.

Laser power is defined as the rate at which energy is generated by the laser. For example, 1W means that 1 Joule of energy is generated in 1 second. Hence, the amount of laser energy delivered depends on the length of time or 'pulse duration' that the laser is left on a particular power level. Therefore, the pulse energy generated in a single laser pulse depends on the pulse duration and the output power level during the pulse. For the same output power level, pulsing the laser beam means that greater energy release occurs because of the very short pulse duration. Coupled with the size of area irradiated by the laser beam, greater energy release produced by pulsing often determines the effects on the tissue, whether the beam coagulates, vaporizes or fragments it.

When laser energy strikes the target tissue for a certain length of time, there is a thermal interaction produced and the tissue has to be allowed to cool by the operator when the laser is used in continuous mode, whereas in both gated and free-running pulsed modes there is enough time between pulses for thermal relaxation to take place. This has to be taken into consideration when deciding which mode to use in certain clinical situations when performing soft tissue surgery. Although pulsed mode is somewhat slower, it is better used on thin fragile tissue to avoid thermal damage to the target tissue and its adjacent area. In addition, the presence of a gentle air stream delivered alongside the laser beam in the hollow waveguide greatly reduces the thermal effect. This is supplemented by using high volume suction, which cools the surgical site. Thick fibrous tissue, on the other hand, should be removed using continuous laser energy to allow for more rapid tissue removal without thermal damage.

Tissue interactions

As with normal light, laser light can interact with tissue in four basic ways:[4]

- Reflection: off the surface without penetration or interaction of the light energy with the tissue.
- Transmission: a portion of light may be transmitted through the tissue unchanged as if transparent to the laser beam.
- Absorption: some of the light may be absorbed into a component of the tissue, in which case there will be transference of energy to the tissue.
- Scatter: the remaining light may penetrate the tissue and be scattered without producing a noticeable effect on the tissue.[5]

These laser tissue interactions are not exclusive and occur in varying proportions within tissues owing to the chemical and molecular variations found within these complex biological systems. The extent of the interaction is usually proportional to the level of absorption of a particular wavelength by tissue.

Tissue elements that absorb a particular wavelength or spectrum of light energy to a high degree are called chromophores. All matter has this property of absorption specificity and this controls how it reacts to incident radiation. This characteristic of preferential absorption of specific wavelength of radiant energy by chromophores within tissue allows for the unique interactions that occur between the monochromatic light energy of lasers and various tissue elements. The laser wavelength will affect certain components of the target tissue; the water content, the colour of the tissue, and the chemical composition, which are all inter-related. For example, oral soft tissues are largely composed of water, which predominantly controls the tissue effects of laser emissions within the infrared spectrum, such as CO_2. This means that the CO_2 laser energy is absorbed very efficiently by tissue fluids and has little penetration beyond the surface.[5] On the other hand, water is comparatively transparent to the emission of the Nd:YAG laser, which accounts for its tendency to penetrate deeper into tissue.

The main beneficial effect of laser energy is absorption of the light by the target tissue and the transfer of this laser energy, thus causing a tissue interaction (photobiological effects). There are four basic interactions that can occur following absorption of laser energy:

- Photochemical: certain wavelengths of laser light are absorbed by naturally occurring chromophores or wavelength-specific light absorbing substances that are able to induce certain biochemical reactions at cellular level. Derivatives of naturally occurring chromophores or dyes have been used as photosensitizers to induce biological reactions within tissues for both diagnostic and therapeutic applications. Photochemical interactions include biostimulation, photodynamic therapy, and tissue fluorescence. Certain biological pigments, when absorbing laser light, can fluoresce, which can be used for caries detection within teeth. A laser can be used in a non-surgical mode for biostimulation of more rapid wound healing, pain relief, increased collagen growth and a general anti-inflammatory effect. A recent addition to the dental market is an example of a photodynamic interaction where light absorbing molecules are employed to produce in tissue a biochemically reactive form of oxygen. This approach involves a 635 nm laser used to activate a solution of tolonium chloride placed in a carious cavity or root canal. Activation of the tolonium chloride releases oxygen species which disrupt the membranes of micro-organisms found in caries, periodontal pockets and root canals (Photo Activated Disinfection, Denfotex Ltd, Unit 15, Belleknowes Industrial Estate, Inverkeithing, Fife UK).
- Photothermal: light energy absorbed by the tissues is transformed into heat energy which then produces tissue effects:
  - photoablation is the removal of tissue by vaporization and superheating of tissue fluids;
  - coagulation and haemostasis; and
  - photopyrolysis or the burning away of tissue.

The amount of laser energy absorbed by tissues largely determines the thermal interaction produced and is in turn dependant on the wavelength of the laser light to a great degree, but also on other parameters such as spot size, power density, pulse duration and frequency, and the optical properties and composition of the tissue irradiated. As mentioned above, the CO_2 laser wavelength at 10,600 nm is highly absorbed by the water content of oral soft tissues, whereby 90% of the energy is absorbed within the first 100 microns of penetration of the tissue surface.[6] Hence, even at relatively low power densities using a focused beam, there is rapid tissue vaporization of the water with charring and burning of the organic content of the tissue.

Photothermal interactions cause the irradiated target tissue to absorb the laser energy and converts it into heat, thereby producing a direct temperature rise in the irradiated tissue volume. When this energy is applied for long enough, heat conduction will cause a temperature rise in surrounding tissues as well. Hence, thermal effects, such as coagulation necrosis, are produced indirectly in collateral areas and are one of the mechanisms responsible for haemostasis when cutting or vaporizing with a laser.

Heat dissipation or diffusion from the irradiated tissue site will determine the extent of collateral damage seen and is largely dependant on the thermal conductivity of the tissue. The time required for diffusion of the heat or 'thermal relaxation time' is defined as the time required for the accumulated heat energy within the tissue mass to cool to 37% of its original value.[7] The degree of heat conduction and rate of tissue cooling both determine the extent of collateral tissue damage for a given wavelength of laser light and tissue type. The composition of the tissue in terms of its structure, water content and vascularity will greatly determine heat conduction/tissue cooling and therefore collateral damage. In addition, factors such as the volume and surface area of tissue irradiated have influence on the rate of heat dissipation.

With continuous laser emission there is no thermal relaxation time, but with pulsed emissions there are brief periods of time allowing for heat dissipation or cooling between pulses.[8] Tissues should be allowed a period of cooling approximately three times their thermal relaxation time to avoid accumulation of heat energy in surrounding tissue and therefore collateral damage. This can be managed effectively using a combination of appropriate power density and pulse duration for the desired procedure.[9,10]

- Photomechanical and photoelectrical: these are non-thermal interactions produced by high energy short pulsed laser light. They include photodisruption, photodisassociation, photoplasmolysis and photoacoustic interactions. Absorption of laser energy pulses results in rapid expansion or generation of shock waves that are capable of rupturing intermolecular and atomic bonds (photodisruption or photodisassociation). Hence, there is transformation of the laser light energy to vibrational or kinetic energy. The pulse of laser energy on hard dentinal tissues can produce a shock wave, which could then explode or pulverize the tissue, creating an abraded crater. This is an example of the photoacoustic effect of laser light.[11]. Photoplasmolysis is a process of tissue removal through the formation of electrically charged ions and particles that exist in a 'plasma' state, a semi-gaseous, high-energy state which is neither solid, liquid, or gas. Ionization of atoms occurs at very high-energy densities followed by plasma formation. The plasma state is maintained by the absorption of energy from the incident laser beam and through electron vibrations causes the rapid expansion and contraction that produces the disruptive shock waves that break apart target materials in photoplasmolysis.

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Abstracts

POST CROWNS NEED MORE THAN JUST CEMENTING

Effect of surface treatment of prefabricated posts on bonding of resin cement. A Sahafi, Peutzfeldt, E Asmussen and K Gotfredsen *Operative Dentistry* 2004; **29**: 60–68.

This *in vitro* study evaluated the effect of various surface treatments of prefabricated posts of titanium alloy (*ParaPost XH*), glass fibre (*ParaPost Fiber White*) and zirconia (*Cerapost*) on the bonding of two resin cements; *ParaPost Cement* and *Panavia F* by a diametral tensile strength test. The treatments were: 1) roughening by sandblasting and hydrofluoric acid; 2) application of primer by coating with *Alloy Primer*, *Metalprimer II* and *Silane*; 3) a combination of roughening with sandpaper and application of a primer or in the form of the *Cojet* system. Some treatments had no effect, but the conclusions may be very helpful to practitioners looking for long-term success when cementing or bonding these restorations. It was found that: 1) *ParaPost Cement* bonded better to titanium alloy and glass fibre posts, while *Panavia F* bonded better to zirconia posts; 2) for the titanium posts all the treatments improved bonding with both resin cements; 3) for the zirconia post the *Cojet* treatment improved the bonding of both resin cements, while sandblasting followed by silane application improved the bonding of *Panavia*.

Simple cementation may not be sufficient for long-tem success.

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