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Laser in Orthodontics

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1. Introduction

1.1 Preface

For many years research in Laser supported therapies in Dental Sciences is progressing steadily. There is no field of dentistry where development took place at such a tearing pace in recent years as in the field of laser dentistry. In the beginning it was only in some branches of this scientific field where significant therapeutic advantages compared to conventional forms of treatment could be reached, but by now this development already includes all branches of dentistry and integrates them into the spectrum of laser supported dental treatment. A great variety of different wavelengths always presents new possibilities of use with constantly new partly almost unbelievable –accomplishments. Everyone who wants to conduct conscientious dentistry in the future inevitably has to integrate the advantages of laser substitution into his or her therapeutic strategy.

1.2 History

Laser' is an acronym for 'light amplification by the stimulation emission of radiation'. Its theoretical basis was postulated by Albert Einstein. In explaining the photoelectric effect, Einstein assumed that a photon could penetrate matter, where it would collide with an atom. Since all atoms have electrons, an electron would be ejected from the atom by the energy of the photon, with great velocity. Einstein also predicted in 1917 in Zur Theorie der Strahlung (Theory of Wavelength), that when there exists the population inversion between the upper and lower energy levels among the atom systems, it was possible to realize amplified stimulated radiation, ie laser light. Stimulated electromagnetic radiation emission has the same frequency (wavelength) and phase (coherence) as the incident radiation. (Einstein, 1905, 1917)

The laser was demonstrated for the first time in 1960 by Maiman after the pioneering the oretical work of Basov, Prokhorov and Townes (Schawlow &Townes, 1940, 1949, 1958, 1994) Many other kinds of laser were invented soon after the solid ruby laser – the first uranium

laser by IBM Laboratories (in November 1960), the first helium-neon laser by Bell Laboratories in 1961 (Javan et al)and the first semiconductor laser by Robert Hall at General Electric Laboratories in 1962; the first working neodymium-doped yttrium aluminium garnet (Nd:YAG) laser and CO2 laser by Bell Laboratories in 1964, argon ion laser in 1964, chemical laser in 1965 and metal vapour laser in 1966. In each case, the 'name' of the laser was annotated with regard to the active medium (source of laser photons) used.

There is a specific and fundamental relationship between light wavelength and absorption by an 'illuminated' target material. Thus, the unique nature of laser light and its specific absorption, led to an expansion of its use in medicine. Within a year of the invention, pioneers such as Dr Leon Goldman began research on the interaction of laser light on biologic systems, including early clinical studies on humans (Goldman et al., 1964)

Although Maiman(1960) had exposed an extracted tooth to his ruby laser in 1960, the possibilities for laser use in dentistry did not occur until 1989, with the production of the American Dental Laser for commercial use. This laser, using an active medium of Nd:YAG, emitted pulsed light and was developed and marketed by Terry Myers(1989), an American dentist. Though low-powered and due to its emission wavelength, inappropriate for use on dental hard tissue, the availability of a dedicated laser for oral use gained popularity amongst dentists. This laser was first sold in the UK in 1990.In 1989, experimental work by Keller and Hibst (1989) using a pulsed Erbium YAG (2,940 nm) laser, demonstrated its effectiveness in cutting enamel, dentine and bone. This laser became commercially available in the UK in 1995 and, shortly followed by a similar Er,Cr:YSGG (erbium chromium: yttrium scandium gallium garnet) laser in 1997, amounted to a laser armamentarium that would address the surgical needs of clinical dentistry in general practice .

1.3 Laser definition

As explained before the word laser is an acronym for Light Amplification by Stimulated Emission of Radiation. The scientific rationale for the use of lasers in dentistry can be reviewed in that context. Light is a form of energy that travels in a wave and exists as a particle.[1] this particle is called a photon.

Laser is an acronym which completely describes the whole physical process of the generation of light. The laser is in fact energy transformer. Different kinds of energy, such as light, kinetic of electrical energy, are transformed into a new kind of optical energy with special properties. This new kind of optical energy is completely artificial and cannot be found anywhere in nature. Based on this consideration, it can be stated that a laser transforms energy of "low quality" into a kind of energy which has "high quality" (Meister, 2007).Special materials with well defined properties must be used to transform the energy during the simultaneous generation of light. These materials can be gases, Liquids, Semiconductor materials, glasses or artificial gemstones (crystals), and moving charged particles. Therefore, the systems will be classified as gas, dye, semiconductor, solid-state and free-electron laser (Meister, 2007).

The component parts of a typical laser are:

1. Active medium

A material, either naturally occurring or man-made that when stimulated, emits laser light. This material may be a solid, liquid or gas. The first 'dental' laser used a crystal of neodymium-doped yttrium Aluminium garnet (Nd:YAG) as its active medium. 'YAG' is a complex crystal with the chemical composition Y3Al5O12. During crystal growth, 1% neodymium (Nd3+) ions

are doped into the YAG crystal (Parker,2007).The active medium is positioned within the laser cavity, an internally-polished tube, with mirrors co-axially positioned at each end and surrounded by the external energizing input, or pumping mechanism.

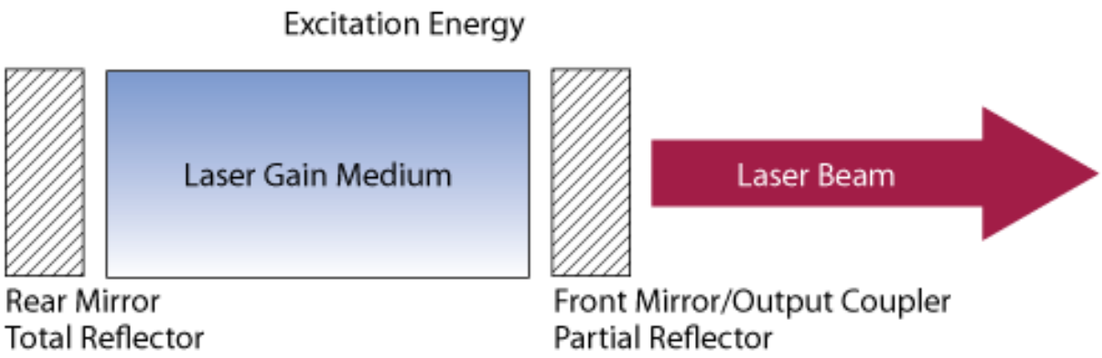


Fig. 1. The component parts of a typical laser

2. Pumping mechanism

This represents a man-made source of primary energy that excites the active medium. This is usually a light source, either a flashlight or arc-light, but can be a diode laser unit or an electromagnetic coil. Energy from this primary source is absorbed by the active medium, resulting in the production of laser light. This process is very inefficient, with only some 3-10% of incident energy resulting in laser light,9 the rest being converted to heat energy.

3. Optical resonator

Laser light produced by the stimulated active medium is bounced back and forth through the axis of the laser cavity, using two mirrors placed at either end, thus amplifying the power. The distal mirror is totally reflective and the proximal mirror is partly transmissive, so that at a given energy density, laser light will escape to be transmitted to the target tissue(Parker,2007). (Fig.1)

1.4 Delivery system

Dependant upon the emitted wavelength, the delivery system may be a quartz fiber-optic, a flexible hollow waveguide, an articulated arm (incorporating mirrors), or a hand-piece containing the laser unit (at present only for low-powered lasers). Early attempts to produce delivery systems relied upon the use of fixed mirror and/or lens apparatus. Therefore, shorter wavelengths such as argon, diodes and Nd:YAG can enjoy such fiber delivery, whereas longer wavelengths (Er,Cr:YSGG, Er:YAG and carbon dioxide) give rise to severe power losses through quartz fiber and hence require alternative delivery systems (Merberg,1993;Inberg et al.,1998;Konorov et al.,2004).

1.5 Characteristics of laser light

A wave of photons has 3 basic properties:
(1) A constant velocity (the speed of light).(2) Amplitude (the vertical measurement of the height of the wave, from top to bottom). This is a measurement of energy of that wave, expressed as a joule, or 1 unit of energy. In dental applications, a useful quantity is a mill joule, one thousandth of a joule.(3) Wavelength (the horizontal distance between any 2 corresponding points of the wave).

Both ordinary light and laser light consist of waves. However, laser light is distinguished from ordinary light by the following 2 properties :(1) Laser light is generated as only 1 colour, a property called monochromaticism. This color can be either visible or invisible to the human eye, but is described as the measurement of the wavelength, which, for dental lasers, is expressed in nanometres (one billionth of a meter).(2) The waves of laser light are coherent for all lasers. Each wave is identical in physical size and shape. This monochromatic, coherent wave of light energy emerges from the laser device as a precise, collimated beam. These properties make the laser beam a uniquely efficient source of energy (Meserendino & Pick, 1995).

1.6 Model of operation

Laser sources can emit light continuously or in pulsed fashion. The difference is related to the time –limited emission of such a system. In what is known As: continuous-wave" (CW) mode. Carbon dioxide, argon, and diode lasers operate in this manner.If the time – limited emission is less than 0.25 s. the laser emits light in so-called "pulse" mode. Free-running pulse, which has very short bursts of laser energy, with each pulse being a few 10 thousandths of a second in duration. Nd and Er:YAG, as well as Er,Cr:YSGG devices operate as free-running pulsed lasers.A special case of pulsed laser operation is the chopped mode. A continuously emitting laser beam is interrupted at regular intervals using different kinds of apertures through which the light can pass. Compared to the regular pulse operation of a laser, the apertures are placed outside the Laser Set-up where the energy is transformed.

1.7 Laser types in dentistry

A wide variety of laser systems have been established in dentistry (Wigdor et al., 1995). The available radiation is emitted from the blue spectral range up to the mid-infrared region. Numerous different applications have been developed, depending on the varying parameters of the emitted laser light. It is important to know what kind of laser is suited to a specific indication, in order to get the maximum benefit by implementing this technology in dental practice (Meister, 2007).

1.7.1 The argon ion laser

Ionized gases and vapors represent only a small segment of the range of media suitable for use in lasers. The idea of using ionized noble gases as laser media was realized technically by Gordon et al. in 1964, i. e., again in the early years of laser development. Noble – gas ion lasers using argon, krypton and xenon are among the most powerful continuous-wave lasers in the visible range of the spectrum. Especially in dentistry, the Argon ion laser is used, for example, for soft-tissue surgery, photo-polymerization and decay prevention (Mattson et al. 1998, Powell et al. 1995, Anderson et al. 2002, Hicks et al. 2004).

Argon's strongest emission lines at 488 nm and 514.5 nm are of relevance for dental applications. The 488 nm line and lines beneath are used for photo- polymerization caused by absorption in campherchinone, and the 488/514.5 nm combination is suitable for soft-tissue surgery due to the high absorption in melanin, hemoglobin and oxyhemoglobin.

1.7.2 The helium – neon laser

The Helium- neon laser was not only the first gas laser, but also the first continuous-wave laser in the history of laser development (Javan et al. 1961). It is the typical representative of

the class of neutral- gas atomic lasers.Thanks to its visible emission line at 623.8nm and owing to its outstanding optical properties; this laser is commonly used as a tool for adjusting optical and mechanical systems, in holography and interfermetry, as well as in applications in biology and medicine. Its in expensive production also contributes to the worldwide use of this laser. It is thus not surprising that a laser of this kind operating at the above wavelength was also the first to be used in photodynamic therapy (Dougherty 1993) and low – level laser therapy (Saperia et al. 1986, Gomi et al. 1986, Bihari & Mester 1989).He-Ne lasers operating with various wave-lengths in single-line and multi-line dome are available commercially. Their emission range extends from intermediate and near infrared (3391, 1523, 1152, nm), red (640, 635, 632.8, 629 nm), orange (612, 604 nm) and yellow (594 nm) all the way to the green (543 nm) spectral range . The output power of these systems varies between <1 mW to several 10 Mw (3391 nm and 632.9 nm)the power generally being increased exclusively by extending the amplification path.

1.7.3 The semiconductor laser

Laser activity in semiconductor crystal was first observed in 1962 (Hall et al., Nathan et al., Holonyak et al., Quist et al.). So-called semiconductor or diode lasers emit coherent radiation in the ultraviolet (UV), visible(VIS) and infrared (IR) spectral ranges. The first semiconductor lasers were pulsed and operated at low temperatures. Not until 1970 was continuous – wave operation at room temperature achieved. Suitable semiconductor compounds are the elements of Groups II to VI the periodic table. They primarily include gallium –arsenide (GaAS) compounds, with mixed crystals including elements from Groups III to V being of particular importance. Diode lasers that are based on the elements gallium and arsenic and arsenic and emit in the range of 700-1,000 nm, i.e., in the near IR region of the spectrum, have become increasingly important in recent years. Especially in dentistry, 810 and 980 nm had become the most important wavelengths for using these lasers in endodontics and periodontics (Kimura et al. 2000, Aoki et al. 2004).

1.7.4 The neodymium: YAG laser

The Neodymium: YAG laser was developed in 1964 (Geusic et al. 1964) and is the classical and most widely used solid- state laser. Emitting its strongest fundamental wave length at 1,064 nm, the Neodymium : YAG laser is characterized by a relatively simple set – up and the generation of high output powers, both in pulsed mode at high repetition rates (up to 10 kHz) and in continuous wave mode (Geusic 1966) .The actual laser process takes place in the neodymium ion (Nd^{3+}). Neodymium belongs to the group of rare earths (lanthanides) and is embedded in a host crystal consisting of Yttrium – Aluminium –Garnet (YAG, $Y_3A_{l5}O_{12}$).

1.7.5 The erbium family lasers

Since 1988 Erbium lasers are the mainly used laser systems in dentistry for cavity preparation (Paghdiwala 1988, Hibst et al. 1089, Keller 1989). Their emission wavelengths are in the spectral range from 2.6 to 3 µm and are perfectly matched to the absorption maximum of water and the OH- groups, also found as components of dental tissue. Two Erbium laser systems are preferred dentistry: first, the Erbium: YAG laser, which emits light at 2.94 µm (Zharikov et al. 1975), and second, the Erbium, chromium: YSGG laser, which emits light at 2.79 µm (Zharikov et al. 1984, Moulton et al. 1988).In general, Erbium lasers are excited by flash lamps. This implies that these lasers cannot run in continuous-wave mode due to the

long lifetime of the lower laser level. In pulsed mode, however, Erbium lasers can be operated up to a pulse repetition rate of 40 Hz and average powers of 20 W at pulse energies of 1 J.

1.7.6 The carbon dioxide laser

The Carbon dioxide laser is the most powerful gas laser. Its technical realization was achieved by Patel in 1964 (1964 a,b) .In dentistry , use is generally made of low power sealed tubes with CW output powers of up to 50 W and pulsed – mode outputs of up to 300 W. The transformer or active medium of a Carbon dioxide laser is a mixture of Carbon dioxide (laser gas), nitrogen (excitation gas) and helium (cooling gas). The preferred laser transitions occur at 9.6 and 10.6 μm, with the emission at 10.6 μm describing the strongest laser transition. The Carbon dioxide laser is used for a variety of purposes in dentistry. Its strong absorption in water and hydroxyl apatite (maximum at 9.6 μm) makes it an ideal instrument for surgery on soft and hard tissue.

1.8 Light – Tissue interaction

When electromagnetic radiation hits biological tissue, different interactions occur as a function of various physical parameters. The processes occurring during the propagation of light in so- called turbid media can be divided into three cases (Hall and Girkin 2004):

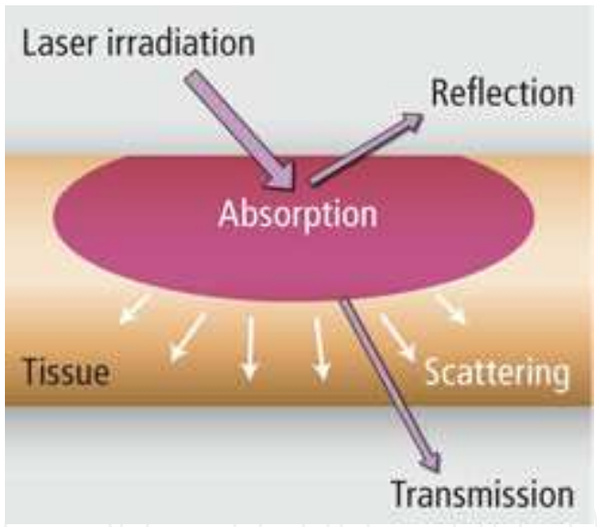


Fig. 2. What happens when Laser hits the tissue?

- Reflections on the tissue surface Reflection is a surface phenomenon (Fresnel reflection), resulting in the change in direction of the light wave caused by single interaction with a large object, the direction of the reflected wave often being opposite the incident wave. In reflection, wavelength or photon energy of the light wave is not altered.(Fig.2)
- Interactions in the tissue

Absorption

The energy of the light is absorbed by the object and then converted into a different form such as heat, for instance. An object can also absorb the energy of the light and then reemit this energy as another light which has less energy. This process is well known as florescence. (Fig.3)

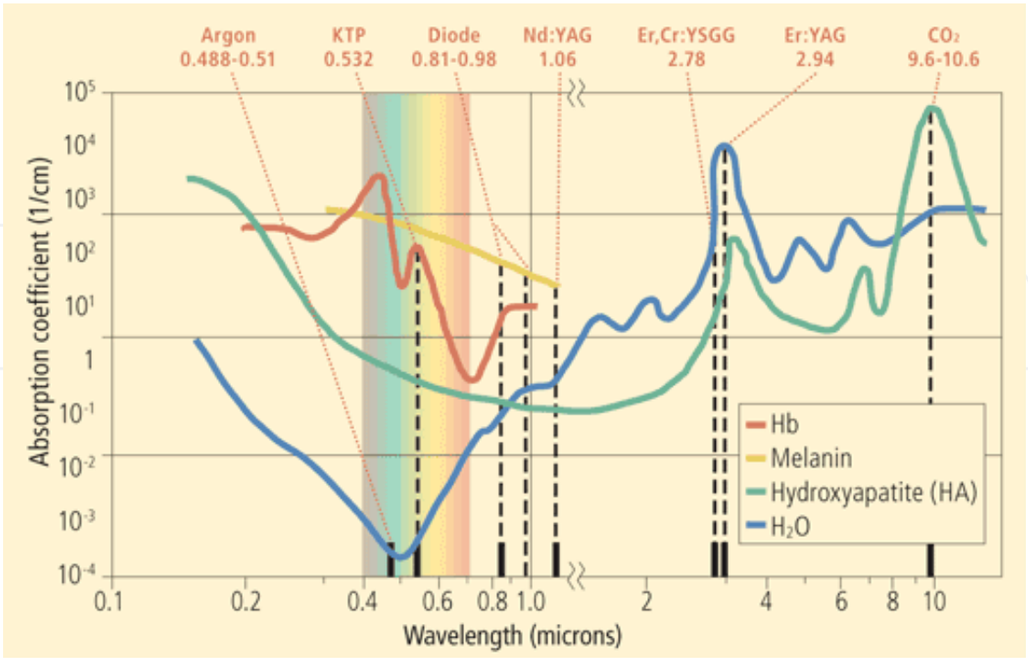


Fig. 3. Absorption curve of various tissue components.

Scattering

Scattering is the change in direction of a light wave on single or multiple occasions when it interacts with a small particle or object within inhomogeneous and/or turbid materials. The scattering of a light wave with the objects may, or may not, cause a change in the energy of the incident light wave, resulting in absorption, diffuse reflection or diffuse transmission. The angle or quantity of scattering depends on the relative sizes of the wavelength and the particles.

- Penetration of the tissue
- The wave is not influenced by the material. The energy and direction of propagation of the wave of incident is not changed during transmission. The light is transmitted as a collimated beam (Meister, 2007).

In short, laser-tissue interactions depend on the interplay of irradiation parameters: 1) wavelength or wavelength band of that particular laser source; 2) physical properties of the tissue irradiated with that particular wavelength or wavelength band; 3) irradiance or pulse energy; 4) continuous wave (CW) or pulsed irradiation; 5) laser beam size on the tissue; 6) irradiation duration or laser pulse length and repetition rate; and 7) any change in the physical properties of the tissue as a result of laser irradiation with the parameters (3-6) above(Cilesiz,2004). At low irradiances and/or energies, laser-tissue interactions are either purely optical or a combination of optical and photochemical or photobiostimulative. When laser power or pulse energy is increased, photothermal interactions start dominating. Finally, photomechanical (sometimes referred to as photoacoustic) effects become apparent when repetitive and very short laser pulses are delivered to the tissue. Therefore there are five interaction mechanisms associated with the use of lasers in biomedicine: 1) purely optical, e.g., fluorescence spectroscopy for cancer screening, optical coherence tomography (OCT) for high-resolution imaging; 2) photochemical (causes target cells to start light-induced chemical reactions.), e.g., photodynamic therapy (PDT); photobiostimulative, e.g.,

laser acupuncture;3) Photoablative,(causes photodissociation or breaking of the molecular bonds in tissue.) 4) photothermal(converts light energy into heat energy. This causes the tissue to heat up and vaporize.), e.g., laser-assisted refraction correction by ablation of parts of cornea, tattoo removal; and 5) photomechanical (photoacoustic),(causes dielectric breakdown in tissue caused by shock wave plasma expansion resulting in localized mechanical rupture.) e.g., laser lithotripsy.

A comparative plot of laser-tissue interactions as a function of exposure time and irradiance is given in Fig. 4. Niemz (2002) emphasizes that all laser-tissue interaction mechanisms share a common datum: characteristic energy density varies typically between 1 and 1000 J/cm^2, whereas irradiance varies over 15 orders of magnitude. Consequently, laser exposure duration is the parameter that determines the nature of laser-tissue interactions. (Cilesiz, 2004)

Niemz (2002) has also determined that all effects with near-infrared laser wavelengths at pulse durations of 1 microsecond or greater are thermal in nature. There are 5 factors to consider regarding heat generation by these lasers:(1) wavelength and optical penetration depth of the laser;(2) absorption characteristics of exposed tissue;(3) temporal mode (pulsed or continuous);(4) exposure time; and(5) power density of the laser beam.

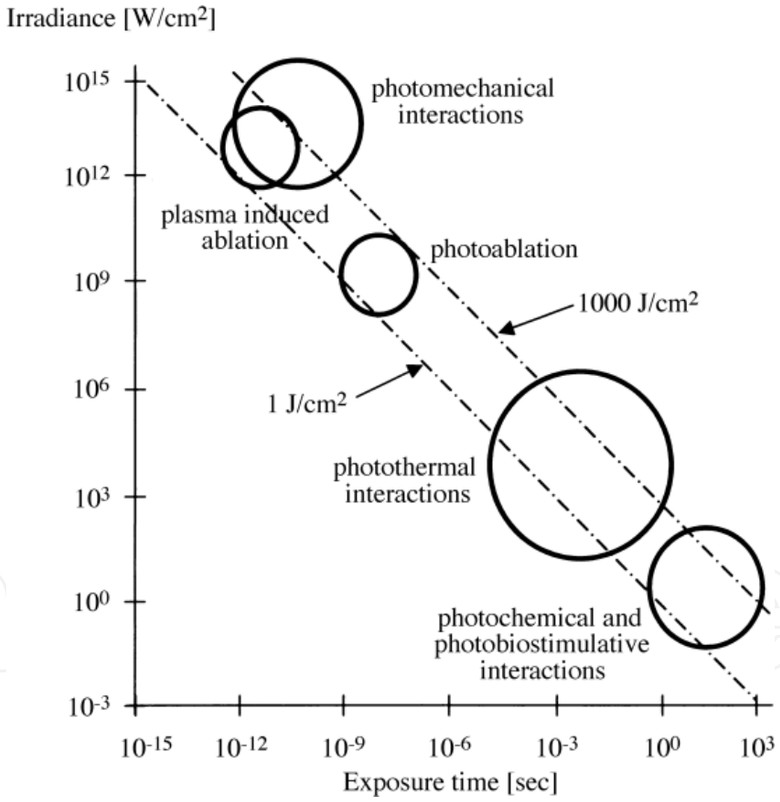


Fig. 4. Representation of laser-tissue interactions in terms of exposure time and irradiance

2. Diagnostic lasers

2.1.1 Tree-dimensional laser scanning and reconstruction (holography)

Three-dimensional (3D) laser scanners are increasingly being used in orthodontics to establish databases for normative populations (Yamada et al. 2002) and cross sectional

growth changes (Nute and Moss 2000), and also to assess clinical outcomes in orthognathic surgical (McCance et al. 1992, Ayoub et al. 1996, McCance et al. 1997, Ayoub et al. 1998, Ji et al. 2002, Khambay et al. 2002, Marmulla et al. 2003) and nonsurgical treatments (McDonagh et al. 2001, Ismail et al. 2002, Moss et al. 2003, Jang et al. 2009).
The basic concepts of the system have been described by Arridge et al (1985). The laser system consisted of two vertically fanned out low power helium-neon laser beams which were projected on to the face and viewed from an oblique angle by a television camera. In 1988 Ayoub et al. (1996) developed a video-capture stereoscopic method of imaging. Two pairs of stereo cameras ensured that the curved facial surfaces were completely imaged within 2 seconds. The system allowed photo-realistic image generation of the face that could be viewed from any direction. This polygonal facial model could be used to measure facial landmarks and volumes. Various applications of laser holography in orthodontics are:

2.1.2 Facial soft tissue analysis

The recent emphases on soft tissues as the limiting factor in treatment and on soft-tissue relationships in establishing the goals of treatment has made 3D analysis of soft tissues more important in diagnosis and treatment planning. It is equally important to be able to detect changes in the facial soft tissues produced by growth or treatment. With advancement in technology, laser-scanning devices are now smaller and can be assembled in any location for studies on facial morphology (Kau et al. 2004). The scanning process is non-invasive and normally completed within a few seconds. Furthermore, the data acquired is accurate to approximately 0.5 mm, depending on the technique used (Arridge et al., 1985; Moss et al., 1987, 1988, 2003; Nute and Moss 2000; Kau et al., 2005). These systems are valuable tools for their ease of application and creation of 3D images. It has been stated that there are many advantages of laser scanners over other types of 3D imaging technology in terms of cost, speed, and portability (Sholts et al. 2010).

2.1.3 Digital models

Orthodontic study models are usually collected by clinicians to aid diagnosis, monitor treatment, and complement the written record. Study models are also used in research, audit, and teaching. The need to retain dental casts for future reference has created storage problems for orthodontists (McGuinness and Stephens, 1992). The holograms offer a more convenient and cost-effective means of recording and maintaining this information accurately. These computer-based digital orthodontic models have the potential for assessing tooth size, arch form, and tooth–arch discrepancies (Alcaniz *et al.*, 1999; Lu *et al.*, 2000; Hirogaki *et al.*, 2001; Santoro *et al.*, 2003; Quimby *et al.*, 2004). Some investigators have performed 3D superimposition of dental casts to analyze orthodontic tooth movement (Ashmore et al. 2002, Hayashi et al. 2002, Hayashi et al.2004, Yao et al. 2005, Cha et al. 2007).
It has been claimed that most parameters on the digital models can be reliably measured, and digital models can potentially eliminate the requirement for the production and storage of dental casts (Asquith et al. 2007). In recent times the cost limitation of laser linear scanning has been addressed by high throughput commercial production.

2.2 Laser Doppler flowmetry

The laser Doppler flowmetry (LDF), developed in the 1970s as a noninvasive electro-optical technique to measure the velocity of red cells in skin capillaries, has been used for the

diagnosis of pulp vitality in human teeth (Gazelius et al. 1986). The original technique utilized a light beam from a helium-neon (He-Ne) laser emitting at 632.8 nm, which, when scattered by moving red cells underwent a frequency shift according to the Doppler principle. A fraction of the light back-scattered from the illuminated area, shifted frequency in this way. This light was detected and processed to produce a signal that was a function of the red cell flux. This information was used as a measure of blood flow, the value being expressed as a percentage of full-scale deflection at a given gain. Other wavelengths of semiconductor laser have also been used: 780 nm and 780-820 nm (Kimura et al. 2000). Zang et al. (1996) demonstrated greatly improved results using forward scattering detection as opposed to conventional backward scattering detection. These results were confirmed by Sasano (1998). Odor et al. (1996) reported that the 810 nm wavelength showed good sensitivity but poor specificity and that the 633 nm wavelength showed good specificity but poor sensitivity. In general, infrared light (780-810 nm) has a greater ability to penetrate enamel and dentine than shorter wavelength red light (632.8 nm) (Vongsavan et al. 1993). The lasers used for LDF are usually at a low-power level of 1 or 2 mW and no reports on pulp injury by this method have been made. Konno et al. (2007) stated that high-powered (5 mW) transmitted laser light could be a better tool for both monitoring the pulpal blood flow of the teeth and assessing tooth-pulp vitality than the conventional back-scattered light flow meter apparatus. It was suggested that this was due to because blood-flow signals did not include flow of nonpulpal origin, and also because the output signals and responses to blood-flow changes were clear and could easily be monitored.

LDF techniques are united in their validity for pulp vitality testing as they reflect vascular rather than nervous responsiveness (Tronstad 1992). Pulpal responses to orthodontic forces or the orthopedic forces created by rapid maxillary expansion have previously been investigated by LDF (McDonald et al. 1994, Barwick & Ramsay 1996, Brodin et al. 1996, Ikawa et al. 2001, Sano et al. 2002, Konno et al. 2007, Babacan et al. 2010). LDF is also a reliable method for blood flow measurements after orthognathic surgery. Among patients who undergo a segmental maxillary osteotomy or Le fort I osteotomy, significant reduction in pulpal sensibility has been noted in teeth in the osteotomized segment or maxilla (Yoshida et al. 1996, Firestone et al. 1997, Harada et al. 2004, Emshoff et al. 2000, Emshoff et al. 2008).

2.3 Laser florescence for caries detection

The early detection and quantification of initial caries formed around orthodontic brackets is a possibility aiming to minimize the damage of caries lesions in orthodontic patients (Aljehani et al. 2004, Staudt et al. 2004). Quantitative methods would be able to detect caries lesions earlier than visual inspection would, and such methods could be used to assess the outcome of preventive interventions (Alencar et al. 2009).

The laser fluorescence (LF) device is a quantitative method based on emission of light from a diode laser at a wavelength of 655 nm and measurement of the fluorescence emitted mainly from the carious tissues. At this wavelength, clean healthy teeth exhibit little or no fluorescence. In contrast, demineralized teeth exhibit fluorescence proportionate to the degree of demineralization, resulting in elevated scale readings on the display. The fluorescence is believed to originate from protoporphyrin IX and related metabolic products of oral bacteria (Konig et al.1998, Lussi et al. 2004, Gostanian et al. 2006). The LF device may be useful for assessing the severity, progression, and depth of white spot lesions during orthodontic treatment (Benham et al. 2009).

Two versions of the LF device are currently available commercially. The older version (DIAGNOdent, Kavo, Biberach, Germany) which was introduced in 1998, is used to detect occlusal and smooth surface caries. The latest version, the DIAGNOdent pen (LFpen) (Kavo), has been designed for easier access to a proximal surfaces (Lussi et al. 2006).
The original LF device has shown good performance and reproducibility for detection and quantification of occlusal and smooth surface caries lesions in in-vitro studies, but the results of in-vivo studies have been somewhat contradictory (Rocha et al. 2003, Anttonen et al. 2004, Astvaldsdottir et al. 2004, Tranaeus et al. 2004, Bamzahim et al. 2005, Angnes et al. 2005, Akarsu and Koprulu 2006, Reis et al. 2006, Abalos et al. 2009, Chu et al. 2009, Khalife et al. 2009). A review by Bader and Shugars (2004) disclosed that although several evaluations of diagnostic performance have appeared in the literature, the range of the LF device performances is extensive. For detection of dentinal caries, sensitivity values ranged widely (0.19 to 1.0) although most tended to be high. Specificity values exhibited a similar pattern, ranging from 0.52 to 1.0. In comparison with visual assessment methods, the LF exhibited a sensitivity value that was almost always higher and a specificity value that was almost always lower. The LF pen has performed as well as the original device on occlusal surfaces in vitro (Lussi et al. 2006). To date, there is only one published study of the clinical performance of the LF pen on occlusal surfaces (Huth et al. 2008).
In general, in vivo studies of LF for occlusal caries detection indicate moderate to high sensitivity and lower specificity (Bader and Shugars 2004, Reis et al. 2006, Abalos et al. 2009, Chu et al. 2009). Therefore, the LF device should be regarded at most as a supplementary aid for detection of caries on coronal surfaces. Recently Alencar et al. (2009) proposed a new approach using the LF devices associated with fluorescent dyes and concluded these devices might be feasible options to be used in clinical association with porphyrins, in order to detect early demineralization around orthodontic brackets which cannot be estimated directly in a clinical situation.

3. High intensity laser therapy in orthodontics

3.1.1 Laser curing of light-cured materials

The application of visible light is necessary for initiating the polymerization reaction of many cements used in orthodontics, including photo-polymerized adhesive resins and some glass ionomer products. Camphorquinone, a photo initiator used in most dental adhesives, activates at wavelengths between 460 and 480 nm (blue region of the visible light spectrum), with a peak at 468 nm (Usumez et al., 2003). It has been demonstrated that at least 300 mW/cm2 of light intensity is required for optimal curing of a 2-mm thick layer of resin composite (Rueggeberg et al., 1994). There are several options for curing of orthodontic cements:

3.1.2 Conventional and fast quartz-tungsten-halogen (QTH) lights

Halogen bulbs use electric energy to heat a quartz-halogen or tungsten-halogen filament to high temperatures. This filament then glows and creates light. In a halogen bulb, only 1 % of electric energy is consumed for generation of light, and the rest is converted to heat, degrading the components of the bulb over time. Lifetime of halogen devices is less than 100 hours, and these are very sensitive to shock and vibration. The light produced by halogen devices has a wide wavelength range, including both ultraviolet and visible lights, necessitating the use of special filters to select blue light for emission. The light intensity of halogen lights may vary between 400 mW/cm2 to 800 mW/cm2. However, the output

power of halogen bulbs is decreased over time, so that many halogen bulbs used in dental offices may have light intensities lower than what is considered optimal for sufficient polymerization of adhesives (Barghi et al., 1994). Curing time of 20 to 40 seconds is recommended when using conventional halogen lights for curing orthodontic adhesives and light-cured resin-modified glass ionomers, respectively (Cacciafesta et al., 2005). This may appear a time-consuming procedure for many clinicians, and therefore several attempts have been made to reduce the curing time by using devices that produce higher light intensities.

Fast halogen lamps have similar construction to conventional bulbs but they produce higher output intensities, exceeding 1000 mW/cm2. This is achieved by using higher-output lamps or application of special light guides that focus the light and concentrate it onto a smaller beam area. This way, curing times can be reduced to half of the time needed for curing with conventional halogen lights. However, limitations of filter technique and thermal problems prevent from further development in halogen devices.

3.1.3 Light emitting diodes (LEDs)

In 1995, Mills (1995) introduced solid-state light-emitting diode (LED) technology to overcome the shortcomings of halogen bulbs in polymerization of light-cured materials. When an electric current flows through junctions of semiconductors, light is generated with little energy loss as heat. LEDs have a lifetime of over 10.000 hours, and show little degradation of output power over time. They require no filters to produce blue light, consume low power for operation and are small, cordless, and resistant to hock and vibration. The curing time of 20 to 40 seconds is recommended when using LED devices for polymerization of orthodontic cements. Several studies indicated that at similar irradiation times, LED units have comparable (Dunn and Taloumis, 2002; Silta et al., 2005; Bishara et al., 2003) or higher (Carvalho Fde et al., 2010) efficiency than conventional halogen devices in polymerization of orthodontic adhesives.

3.1.4 Plasma arc units

Xenon plasma arc lamps were introduced to provide high intensity curing of adhesive materials in dentistry. The device consisted of an anode and a cathode, placed in a quartz tube which fills with xenon gas. When an electron current is passed through xenon, the gas becomes ionized (plasma condition) and generates an intense white light, which should be filtered to deliver blue wavelengths. However, the frequency bands produced by plasma arc units are much narrower than those of halogen lights and therefore less filtering is required. The process of plasma light generation requires a high voltage and generates considerable heat. The lifespan of plasma discharged tubes is several hundred hours. The light intensity is between 1400 to 2400 mW/cm2, (Wendl and Droschl, 2004) therefore less time is needed for polymerization of cements. According to manufacturer' claims, 1 to 3 seconds of irradiation with plasma arc unit is sufficient for polymerization of most dental adhesives. However, Ip and Rock (2004) reported that irradiation time of 2 seconds with plasma light resulted in significantly lower bond strength than 20 seconds of curing with conventional halogen light. It seems that at least 4 to 10 seconds of plasma irradiation should be performed to achieve comparable bond strengths to conventional halogen bulbs.

3.1.5 Argon laser

Argon laser is promising for the polymerization of dental restorative materials because one of the argon laser's emission peaks (488 nm) matches well with the absorption peak of the

photoinitiator, camphorquinone (CQ) in light-curing dental restorative materials. It was claimed that the argon laser can polymerize a light-cured orthodontic adhesive 4 times faster with the same or even higher bond strength (Talbot et al 2000) and with less frequency of enamel fracture at debonding than with the conventional curing light (Lalani et al. 2000). In addition, at recommended curing times, in-vitro pulp chamber temperature increases from the laser units were significantly lower than those of the conventional curing light (Powell et al. 1999). Therefore, the argon laser should not pose a serious thermal risk to the pulp if used at the recommended energies (Cobb et al. 2000, Anic et al. 1996).

James et al (2003) presented in-vitro mean shear bond strength results using adhesive-precoated (APC) brackets for the argon laser (238.1 mW/cm2, 10 seconds) of 4.2 MPa compared with the conventional curing light (771.9 mW/cm2, 20 seconds) of 5.3 MPa. Using a higher intensity argon laser (approximately 800 mW/cm2, 10 seconds) system, Lalani et al (2000) reported similar bond strengths with their conventional curing light (approximately 400 mW/cm2, 40 seconds) group.

Kelsey et al (1989) conducted a carefully controlled laboratory study to determine the optimum power setting and polymerization cycle time to cure 4 commercially available composite resins with an argon laser. The most effective resin polymerization was achieved when Prisma APH was polymerized (310 mW) for 7 seconds, when Herculite was polymerized (160 mW) for 12 seconds, when P-50 was polymerized (525 mW) for 13 seconds, and when Silux Plus was polymerized (270 mW) for 13 seconds. The authors concluded that the exact parameters of laser power and exposure time seem to be material specific, with greater variation noted in power settings than in exposure times. Talbot et al (2000) saw a significant difference between bond strength values at 3 laser energies (200, 230, and 300 mW). Therefore, it seems that the power setting is a major factor in the outcome of bond strength values.

Elvebak et al. (2006) tested the effects of curing time and light intensity on the shear bond strength of adhesive composites for stainless-steel orthodontic brackets. An argon laser at four different power settings (100, 150, 200, and 250 mW) and four different exposure times (5, 10, 15, and 20 seconds) was used to bond APC stainless-steel brackets. They results showed the location of bond failure did not differ significantly in relation to exposure time. However, the location of bond failure was significantly different in relation to light power. They concluded that short exposure time and a low power setting produce shear bond strengths equivalent to those produced by longer exposure times and higher power settings.

To date, little has been reported on the clinical performance of argon laser for orthodontic bracket bonding. Elaut and Wehrbein (2004) completed a 14-month prospective controlled clinical trial to assess the bond failure rate and decalcification incidence with conventional curing light and argon laser curing. There was no significant difference between curing methods for decalcification, but there were statistically fewer bond failures with the argon laser. They concluded that the clinical bond strength was superior with argon laser. Hildebrand et al. (2007) compared bond strengths after curing with the argon laser (10 seconds) and the conventional curing light (40 seconds) in vivo and in vitro. They stated that the bond strength for argon laser curing is comparable to conventional light curing and is sufficient for clinical applications. Although the argon laser left more adhesive on the tooth surfaces on debonding, there was no increase in enamel surface fractures.

Although the usefulness of argon lasers has been well documented, the expense of this laser has prevented it from becoming a popular light-curing source. Recently, Kim et al. (2010) assessed the effectiveness of the diode-pumped solid-state (DPSS) laser with a wavelength

of 473 nm on the bonding of orthodontic brackets to teeth. This recently developed laser is expected to show similar features to the argon laser due to the similar emission wavelength. Furthermore, since this DPSS laser is compact and much cheaper than the argon laser, it has potential applications in dentistry instead of the argon laser. They concluded that the shear bond strength value of the DPSS laser-treated groups was similar to that of the control group (QTH light) and curing with DPSS laser will reduce chair time. However, future experiment is needed to support their claim.

3.2 Enamel conditioning for bracket bonding with laser

Proper conditioning of enamel surface is necessary for bonding of orthodontic attachments to teeth. In orthodontics, as in other fields of dentistry, the most common method of enamel preparation is acid phosphoric etching. Acid etching process prepares the surface by selective removal of interprismatic mineral structure, while the organic materials are less affected. The resultant rough and microfissured surface is very useful for retention of adhesive resins, but these structures are also more vulnerable to caries formation. Acid etching removes and demineralizes the most superficial and protective layer of enamel and makes the teeth more susceptible to long-term acid attack, especially when resin monomers can not sufficiently fill the demineralized area due to saliva contamination or air bubbles (Martinez-Insua et al., 2000). Since the prevalence of white spot lesions is very high among orthodontic patients (Gorelick et al., 1982), prevention of enamel demineralization is of great importance in orthodontics.

There has been extensive research to find an alternative conditioning method to overcome the main disadvantage of phosphoric acid etching, i.e. the potential for producing decalcification. Some researchers have worked on conditioning enamel with polyacrylic acid (Maijer and Smith, 1979) or pretreatment the enamel surface with sandblast of aluminum oxide (Canay et al., 2000) to reduce the rate of enamel loss during etching. However, these methods failed to achieve adequate bond strength to resist intraoral forces.(Canay et al. 2000; Jones et al., 1999)

Laser etching has become an alternative to acid etching of enamel. Laser etching is painless and does not involve either vibration or heat; also, the easy handling of the apparatus makes this treatment highly attractive for routine clinical use (Ozer et al. 2008). Laser etching of enamel creates microcracks that are ideal for resin penetration (Visuri et al. 1996). The surface produced by laser irradiation is also acid resistant. Laser irradiation of the enamel modifies the calcium-phosphate ratio and leads to the formation of more stable and less acid soluble compounds, thus reducing the susceptibility to caries attack (Oho et al. 1990, Klein et al. 2005). Because water spraying and air drying are not needed with laser etching, time can be saved (Usümez et al. 2002, Lee et al. 2003). From a clinical standpoint, saving chair time also improves adhesion because it reduces the risk of salivary contamination.

Different types of laser such as CO2, Er:YAG, Nd:YAG, and Er,Cr:YSGG have been used in orthodontics for enamel conditioning to bond brackets. Kim et al. (2005) and Lee et al. (2003) tested the effectiveness of Er:YAG laser in etching the enamel surface for orthodontic treatment and concluded that Er:YAG laser ablation can be an alternative tool to conventional acid etching.

Fuhrmann et al. (2001) concluded that CO2 and Nd:YAG dental lasers produce enamel conditioning and tensile bond strength sufficient to meet the requirements of bracket bonding. They stated that CO2 laser produces craters of various dimensions, while the

Nd:YAG laser produces honeycomb structures regionally similar to enamel samples from the acid-etch technique. However, Ariyaratnam et al. (1997) believed that the Nd:YAG laser, when compared to 37% phosphoric acid, produces lower bond strength and alters the surface morphology of enamel. In another study, the authors claimed that dentinal surface exposed by the Nd:YAG laser exhibited microcracks and fissures, and concluded that this is not a suitable method for substituting dentinal acid etching (Ariyaratnam et al. 1999).
Ozer et al. (2008) compared Er,Cr:YSGG laser irradiation at 0.75 and 1.5 W with phosphoric acid etching and self etching primer for orthodontic bonding. They stated that varying power outputs of laser irradiation make different etching patterns: 0.75-W laser irradiation had lower shear bond strength, whereas 1.5-W power output showed comparable shear bond strengths with phosphoric acid and self etching primer. Basaran et al. (2007) reported that the mean shear bond strength and enamel surface etching obtained with an Er,Cr:YSGG laser (operated at 1 W or 2 W for 15 seconds) is comparable to that obtained with acid etching. Enamel and dentin surfaces etched with Er,Cr:YSGG lasers show microirregularities and no smear layer (Hossain et al. 1999). More recently Usümez et al.(2002) found that the results of enamel conditioning with Er,Cr:YSGG laser at 2 W of power (20Hz, 100mJ) were similar to those of acid etching. Cutting the power in half (20Hz, 50mJ) significantly decreased the bond strength of the irradiated surface compared to acid etching; however, individual results varied greatly in each case. So they suggested that Er,Cr:YSGG laser by itself cannot be counted as a successful alternative to conventional methods of increasing bond strengths to enamel. This was recently confirmed by Jaberi ansari et al. (2011,in press) who claimed that re-etching with acid phosphoric will be necessary if Er,Cr:YSGG laser is used for tooth preparation or surface treatment.
Although there are some contradicting findings about the use of lasers for enamel etching, this may be due to the different outputs and experimental designs of the studies (Ozer et al. 2008).

3.3 Bonding to porcelain

Sometimes orthodontic attachments should be bonded to porcelain surfaces, a phenomenon which is most commonly seen in adult patients. Conventional acid etching is unable to produce sufficient bond strength of orthodontic brackets to porcelain surfaces. It has been demonstrated that the application of 9.6% hydrofluoric acid for 2 minutes provides suitable surface alterations for orthodontic bonding. (Zachrisson and Buyukyilmaz, 2005) However, the use of hydrofluoric acid can damage the surrounding teeth and soft tissues, if careful isolation of the operating area is not performed. When etching with hydrofluoric acid, the surrounding teeth and soft tissues should be protected with cream, the etchant should be removed with cotton roll, and the area should be rinsed using high-volume suction. Several alternative techniques have been proposed to replace the use of hydrofluoric acid gel in bonding to porcelain surfaces, such as the application of acidulated phosphate fluoride (APF) gels or laser etching.
Li et al. (2000) prepared porcelain with 0.6, 0.9, and 1.2-W Nd:YAG lasers for bonding and concluded that this type of laser in combination with light cure composites created acceptable bond strength to porcelain. It appears that using an Nd:YAG laser not only eliminates the need to rough up the porcelain, it would also eliminate the potential gingival burns associated with HF acid and the need to repolish the porcelain at deband. Furthermore, etching time is considerably shorter with the Nd:YAG laser compared to HF

acid (10 s vs. 3–5 min). The advantage of the Nd:YAG laser in improving the shear bond strength of titanium ceramic interface was also shown by Kim and Cho (2009). A 2-W CO2 laser in superpulse mode was also found to be appropriate for orthodontic bracket bonding to deglazed porcelain surfaces. Akova et al. (2005) believe that the increased bond strength observed in the laser-treated group is related to micromechanical retention.
Poosti et al. (2011) evaluated the shear bond strength of metal orthodontic brackets to porcelain following conditioning by Er:YAG (2-W for 10 s and 3-W for 10 s) and Nd:YAG (0.8-W for 10 s) lasers in comparison to conventional methods. The results revealed that Nd:YAG laser was shown to be an acceptable substitute for hydrofluoric acid while Er:YAG laser with the mentioned power and duration was not a suitable option.

3.4 Increasing the acid resistance of enamel to prevent formation of white spot lesions

One of the most important problems during orthodontic treatment is the occurrence of enamel demineralization around orthodontic appliances. Fixed orthodontic appliances facilitate the adherence of food particles and make tooth brushing more difficult, resulting in increased amount of bacterial plaque around orthodontic attachments. The organic acids produced by oral bacteria dissolve calcium and phosphorus ions from enamel surface, creating the initial sign of demineralization, namely white spots lesions. These lesions are more commonly seen in upper anterior teeth and upper and lower premolars.(Lovrov et al., 2007) The incidence of white spot lesions is significantly higher in orthodontic patients than untreated subjects.(Tufekci et al., 2011) The clinical study of Ogaard et al (1988a) indicated that white spot lesions can be seen in as early as 4 weeks under unfitted orthodontic bands, implying the rapid progression of demineralization around orthodontic attachments. White spot formation is considered a great problem in orthodontic patients, because it detracts from the aesthetic results of treatment and may compromise tooth health by progression to caries cavity. Therefore prevention of caries formation is of great importance in orthodontic patients, especially for those with poor oral hygiene.
There have been extensive attempts to find a method to reduce the incidence of demineralization in orthodontic patients. Some studies (Ogaard et al., 1988b) indicated the efficacy of using daily fluoride mouth rinse in reducing the occurrence of white spot lesions during orthodontic treatment, but excellent cooperation in using a mouth rinse can be achieved in only 13% of patients.(Geiger et al., 1992) Another method to prevent demineralization is to use fluoride releasing composite resins or conventional or resin modified glass ionomer cements for bonding orthodontic attachments,(Dubroc et al., 1994; Marcusson et al., 1997) but some studies (Cook and Youngson, 1988; Fox et al., 1991; Klockowski et al., 1989) reported lower bond strength when using these adhesives, compared to conventional composite resins. Recently, amorphous calcium phosphate (ACP) agents have been considered as promising agents for increasing enamel resistance to decalcification and also to treat white spot lesions in orthodontic patients. Rose (2000a, b) indicated that casein phosphopeptide-amorphous calcium phosphate (CPP-ACP) agent effectively binds with dental plaque, providing a large reservoir of readily available calcium to inhibit demineralization and also to assist remineralization. Despite improvements in materials and preventive measures, enamel demineralization continues to be a great concern for both orthodontists and patients. Therefore, finding new prophylactic measures to prevent demineralization may be a great step towards achieving healthy and aesthetic teeth at the end of treatment.

In 1965 Sognnaes and Stern were the first to report that when the enamel was exposed to ruby laser irradiation, the resistance of enamel to acid attack was improved. To confirm the previous report of Sognnaes and Stern, Yamamoto and Sato (1980) embedded small pieces of lased enamel into several parts of human dentures. After three months, the unlased area of the enamel showed chalky white lesions, whereas no detectable visible change was observed in the lased area. Subsequently, several investigations have demonstrated that treatment with various lasers can reduce the rate of subsurface demineralization in enamel (Nelson et al. 1986, Nelson et al. 1987, Powell et al. 1994, Qiao et al. 2005). There are several theories regarding the mechanisms by which laser irradiation enhances enamel resistance. These theories range from a surface melting through partial fusion and recrystalization of enamel prisms to changes in the enamel's organic matrix (Wigdor et al. 1995). A number of studies have also shown that combining laser irradiation with fluoride treatment could have a synergistic effect on acid resistance (Goodman & Kaufman 1977, Flaitz et al. 1995, Hicks et al. 1993, Hicks et al. 1994, Hicks et al. 1995, Hicks et al. 1997, Moslemi et al. 2009).

Using quantitative microradiography, argon laser irradiation of enamel reduced the amount of demineralization by 30-50% (Duncan et al. 1993, Powell et al. 1994). Fox, Duncan and Otsuka (1992) found that, in addition to decreasing enamel demineralization and loss of tooth structure, CO2 laser treatment reduced the threshold pH at which dissolution occurred by about a factor of five. Lenz et al. (1982) have suggested that the enamel surface is sealed by the laser and is less permeable for the subsequent diffusion of ions into and from the enamel.

In 2001, Hossain et al. used an Er,Cr:YSGG laser to irradiate the enamel or dentin samples at 6 W (67.9 J/ cm2) or 5 W (56.6 J/cm2) pulse energy, respectively, with or without water mist. The results suggested that Er,Cr:YSGG laser irradiation appears to be effective for increasing acid resistance. SEM observations showed that the lased areas were melted and seemed to be thermally degenerated. After acid demineralization, the thermally degenerated enamel or dentin surfaces were almost unchanged. In 2005 Qiao et al. irradiated the enamel and dentin samples with the Er,Cr:YSGG laser at 6 or 4 W for 6 seconds, respectively. They concluded that Er,Cr:YSGG laser irradiation is effective for increasing the acid resistance of dental hard tissue and does not cause thermal side effects.

Kim et al. (2006) compared the effects of Er:YAG laser ablation and of phosphoric acid etching on the in-vitro acid resistance of bovine enamel and found that reduction rate and reduced depth of calcium content along the subsurface was lowest in Er:YAG laser–treated enamel than the acid etched enamel. Hence, they concluded that the Er:YAG laser–treated enamels were more resistant to acid attack than phosphoric acid–etched enamels.

According to these results it may be concluded that laser treatment of enamel of caries vulnerable areas such as around brockets would be a useful strategy in orthodontic patients. However, this would demand further investigation.

3.5 Bracket debonding

Ceramic brackets were introduced in the mid 1980s to supply the demands of orthodontic patients for more aesthetic and invisible appliances. However, ceramic materials have some innate defaults that preclude easy application of them in orthodontics. The low fracture toughness of ceramics may cause partial or complete bracket fracture during removal. This precludes reuse of the same bracket at a corrected position and may result in eye damage, ingestion or aspiration of bracket fragments. In addition, removal of bracket fragment on the tooth may require the use of diamond burs, a process that is time consuming and can

damage the pulp (Vukovich et al., 1991) and enamel surface.(Chen et al., 2007) Another problem with clinical application of ceramic brackets is the high incidence of enamel damage during debonding. Enamel damage, either in the form of enamel fracture or enamel crack, detracts from esthetics of the tooth and may need costly restorative treatment and also can compromise the tooth integrity by increasing the risk of eventual tooth fracture. When the required force for bracket removal exceeds the cohesive strength of the enamel, fracture of the enamel surface is inevitable. The debonding stress of ceramic brackets can exceed 20 MPa, (Theodorakopoulou et al., 2004; Gwinnett, 1988; Odegaard and Segner, 1988) and these forces may be sufficient to fracture the enamel and create severe discomfort in patients who their teeth have been mobilize by orthodontic treatment.(Tocchio et al., 1993)

For debonding of ceramic brackets, special pliers have been used conventionally to apply a sufficiently high force to fracture the bond. However, ceramic brackets are brittle and cannot be removed easily by pliers. Enamel damage and bracket fracture have been reported frequently with conventional debonding of ceramic brackets (Artun, 1997; Bishara et al., 2008; Joseph and Rossouw, 1990) due to the high bond strength combined with the low fracture toughness of ceramics. Some alternative methods have been proposed for weakening the bond immediately before debonding, including ultrasonic and electro thermal devices.(Bishara and Trulove, 1990a; Brouns et al., 1993; Bishara and Trulove, 1990b) With electrothermal method, adhesive resin is softened above a critical temperature (approximately 150 to 200° C) to allow removing the brackets at a significantly reduced force level.(Strobl et al., 1992) The main drawback of instruments that use electric heat element as a heat source is that there is no quantitative control on the amount of delivered heat energy to ceramic bracket, which in turn may excessively heat the tooth during bracket removal. Some studies reported pulp damage after use of electrothermal devices for debonding of ceramic brackets.(Dovgan et al., 1995; Jost-Brinkmann et al., 1992) and consequently these methods failed to achieve popularity among orthodontists.

Since the early 1990s, lasers have been used experimentally for debonding of ceramic brackets. The use of lasers eliminates problems such as enamel tear outs, bracket failures, and pain that are encountered during conventional ceramic bracket removal techniques. Additionally, lasers have the advantage of decreasing debonding force and operation time (Strobl et al. 1992, Tocchio et al. 1993, Mimura et al. 1995, Rickabaugh et al. 1996, Ma et al. 1997, Obata et al. 1999, Abdul-Kader et al. 1999, Hayakawa 2005, Xianglong et al. 2008).

In most previous studies, carbon dioxide lasers whose wavelength is more easily absorbed by the ceramic brackets had been preferred for debonding. Strobl et al. (1992) investigated the removal of polycrystalline and monocrystalline alumina brackets using carbon dioxide and YAG lasers. Their results showed that laser-aided debonding significantly reduced debonding force by thermal softening of the resin. It was also concluded that with the Nd:YAG laser, approximately 69-75% of the incident light reached the enamel surface, which has the potential to cause pain or damage to the tooth structure.

Mimura et al. (1995) used a carbon dioxide laser to investigate the differences in the laser-aided debonding mechanism between 2 adhesives. Unlike previous studies, they applied the force and the lasing simultaneously. They concluded that the laser-focused adhesives tended to be removed with the brackets in the Bis-GMA groups, whereas the adhesives tended to remain on the tooth surface in the MMA groups.

Rickabaugh et al. (1996) and Ma et al. (1997) used carbon dioxide lasers and modified debonding pliers to accurately position the laser beam on the ceramic bracket. In accordance

with previous studies, their results showed significant differences in tensile debonding forces between the control and study groups. They also stated that the bracket could be removed from the tooth with pliers as soon as the adhesive-softening temperature had been reached, and the debonding pliers holding the bracket reduced the possibility of dropping it on the patient. Additionally, quick removal of the bracket prevented the heat energy stored in the bracket from transmitting to the tooth.

Iijima et al. (2010) suggested that the mechanical properties of tooth enamel such as hardness and elastic modulus were not affected by CO2 laser irradiation. Obata et al. (1999) debonded ceramic brackets with the aid of super and normal pulse CO2 lasers. They showed that a Super pulse CO2 laser is better than a continuous one. As they minimized the power levels of the super pulse CO2 laser, they obtained a smaller intrapulpal temperature increase compared to the normal pulse laser. The investigators concluded that using a super pulse CO2 laser for debonding did not cause a risk for the pulp. Recently, Tehranchi et al. (2010) evaluated the effect of super pulse CO2 laser (power density of 50 W, exposure time of 5 s, and duration pulse of 500 μs) on shear bond strength and adhesive remnant index during debonding of ceramic brackets. They showed less debonding force and more adhesive remnant index on the tooth surface in the laser group.

Tocchio et al (1993) used Nd:YAG laser light at wavelengths of 248, 308, and 1060 nm at power densities between 3 and 33W per square centimeter to debond 2 types of ceramic brackets by externally applied stress of either 0 or 0.8 MPa. No enamel or bracket damage was reported as a result of laser debonding. According to the investigators, laser energy can degrade the adhesive resin by thermal softening, thermal ablation, or photoablation. This mechanism causes rapid thermal expansion or burnout and vaporization of the resin, causing a small explosion. The pressure generated by the explosion functions as the debonding force. The rise in intrapulpal temperature as a result of lasing was extremely low, and the maximum temperature increase was 5.1°C.

A high peak Nd:YAG laser at 2.0 J (1.2-ms pulse duration, 5 pulse per second) was used by Hayakawa (2005) to develop an effective method for debonding ceramic brackets. Even though the Nd:YAG laser has a higher degree of enamel transmissibility than the CO2 laser, it has a lower ceramic absorption level that will directly influence the resin by enhancing the effects of thermal ablation and photoablation. In this study, very short lasing time caused an instantaneous resin reaction that produced a localized, instantaneous temperature increase. The investigator stated that the intrapulpal temperature had not increased much (maximum rise was 5.1°C), probably because of this instantaneous reaction of the adhesive resin to the laser. Although the laser energy delivered was too small compared to Strobl et al.'s (1992) application, it was effective because of the millisecond pulses with high peak powers.

Oztoprak et al. (2010) preferred the Er:YAG laser since it has a lesser thermal effect than the Nd:YAG or CO2 laser (Wigdor et al. 1993). They stated that Er:YAG laser is effective for reducing the shear bond strengths of orthodontic polycrystalline ceramic brackets from high values to levels for safe removal from the teeth. These investigators developed a new method to debond ceramic brackets by scanning thoroughly the surface of the brackets for 9 s. This was confirmed by Nalbantgil et al. (2010) which stated that 6 s lasing with the scanning method using the Er:YAG laser may be an effective and safe way to remove ceramic brackets without causing intrapulpal and enamel damage.

Ahrari et al. (2011) used ultra pulse CO2 laser (188 W, 400 Hz) for deboning of chemically-retained and mechanically-retained ceramic brackets and reported that laser-assisted debonding reduced the risk of enamel damage and bracket fracture, and produced the more desirable ARI scores, without causing thermal damage to the pulp.

Yet laser wavelength and mode of operation (continuous pulsed or modulated) should be chosen properly in order to prevent any thermal hazard given to the enamel or pulp.

3.6 Laser welding

Today, most orthodontic appliances are fabricated by joining of different individual components together. However, in-office fusion of wires or other attachments to orthodontic appliances is still a common procedure for construction or repair of appliances during orthodontic treatment to achieve optimal treatment results. In orthodontics, as in other parts of dentistry, fusion can be achieved through soldering, brazing or welding. The only difference between soldering and brazing is the liquidus temperature of intermediate alloy.

3.6.1 Soldering

In soldering, the metal parts are joined by heating them at temperatures below the solidus temperature of substrate metal. A filler metal with liquidus temperature not more than 450°C is applied. The filler metal melts and flows through the interface without affecting the dimension of the joined structure.(Chandra et al, 2000)

Two methods are used for producing the necessary heat to melt the filler: gas blow torch and electrical resistance soldering. The use of gas blow torch is less expensive, but the heat is much more localized in electrical resistance soldering. It should be noted that the interface between a silver solder and stainless steel is more mechanical than alloying, therefore adequate amount of solder should be used to reinforce the junction. (van Noort, 2002)

3.6.2 Brazing

In brazing, the liquids temperature of filler metal is above 450°C and below the solidus temperature of the base metal. Similar to soldering, the filler metal melts and flows, joining metal parts together without affecting the dimensions of the joined structure. Brazing is a common procedure to join the components of orthodontic appliances such as base and wing components of brackets. However, brazing alloys contain traces of cytotoxic cadmium, and also form a galvanic couple that can lead to ionic release of mainly copper and zinc elements. (Eliades, 2007)

3.6.3 Welding

Welding defines the joining of two metal pieces by applying heat, pressure, or both, without the use of an intermediate alloy. In welding, fusion takes place by metallic bonding through a localized union across the interface. Welding is commonly used for joining flat structures such as band or brackets. The only orthodontic wire material that is truly capable of being welded is β-Titanium. Stainless steel is also can be welded to stainless steel, but the joint is not very strong and should be reinforced with solder. Nickel titanium wires cannot be welded or soldered.(Ferracane, 2001)

There are three ways of welding in dentistry.

Pressure welding: Pressure welding is achieved by applying a sufficiently large force to the metal parts to be joined. Pure gold foils can be pressure welded by hand or mechanical condensers.

Spot (resistance) welding: Welding at a spot is called spot welding. This process is used to join flat structures, such as orthodontic bands and brackets and also to join some types of orthodontic wires. In spot welding, the parts to be joined should be pressed firmly together

between two electrodes usually made of copper. Then a high electric current is passed through the system, and since the parts to be joined are less conductive of electricity than the copper electrodes, they will heat up and create a fused localized melted joint. Usually a current of 250 to 750 amperes is used, for a time of between 1/25th and 1/50th second.(Combe, 1981) Spot welding is successful in formation of overlapping joints of stainless steel or other chromium-containing alloys, but should not be used for gold alloys, since they are good conductors of electricity. Electrical resistance welding is suitable for β-Ti wire, the only orthodontic wire that has true weldability.

The strength of the welded joint is enhanced by an increase in the weld area. However, the welded area becomes brittle and susceptible to corrosion, because of precipitation of chromium carbide at temperatures above 500C, a process that is known as weld decay. Therefore, small welds are generally considered better, because fusion is achieved with minimal changes in the original grain structure.

Laser welding: Another method employed for joining metal frameworks is laser welding. To weld dental alloys, Nd:YAG laser is mainly used (Yamagishi *et al.*, 1993; Liu *et al.*, 2002; Iwasaki *et al.*, 2004; Watanabe and Topham, 2004, 2006; Srimaneepong *et al.*, 2005; Watanabe *et al.*, 2006).

In laser welding, laser light is focused on small regions, applying high energy to these areas in a very short amount of time. Heating is mainly focused at the point of application; therefore the surrounding areas do not damage. (O'Brien, 1997) In some studies, laser welded joints showed greater mechanical resistance than that achieved by traditional welding.(Fornaini et al., 2010)

Titanium alloys are commonly used in dentistry for crowns, bridges, partial denture frameworks, and also for orthodontic wires. These cannot be easily soldered by traditional torch-soldering or oven-soldering procedures. This is related to the fact that at temperatures used for soldering procedures, the thickness of the titanium oxide layer increases and it may even debond from the metal surface at higher temperatures. For effective joining of components made of pure titanium, laser welding is a preferred method, because it is associated with a lower thermal influence on the parts being joined, preserves the excellent biocompatibility potential of pure titanium and prevents the risk of galvanic corrosion. (Anusavice, 2003)

Laser welding is recently used in bracket manufacturing as an alternative to brazing. This technique eliminates the need to brazing alloy, reduces the risk of corrosion, and provides acceptable mechanical performance in association with a low risk of joint failure. (Eliades, 2007)

Solmi *et al.* (2004) analyzed the adhesion and proliferation of human gingival fibroblasts placed in direct contact with conventionally soldered and laser-welded orthodontic joints for up to 16 days. Significant differences in counts of survival fibroblasts were observed at all experimental times. The fibroblasts on both the laser-welded and control substrates showed similar patterns. By contrast, on the substrate of the soldered samples, the fibroblasts showed no sign of adaptation at any time during the study. These results highlight the superior biocompatibility of laser welding over brazing.

Testing the cell reactions of osteoblasts, fibroblasts, and keratinocytes, Sestini *et al.* (2006) found a good tolerance of electrical resistance and laser welding, while traditional silver solder was toxic for osteoblast differentiation, fibroblast viability, and keratinocyte growth.

The influence of brazing or welding on tensile strength has not been uniformly determined. In different studies, the factors affecting the mechanical strength of welded joints have been described: wavelength, peak pulse power, pulse energy, output energy, pulse duration, pulse frequency, and spot diameter of the laser welding machine and the type of metal used (McCartney and Doud, 1993; Yamagishi *et al.*, 1993; Taylor *et al.*, 1998; Watanabe *et al.*, 2001, 2003, 2004, 2006; Yan and Yang, 2006). Chai and Chou (1998) showed an equal or superior mechanical strength of the welded sites compared with the unsectioned parent metal of different Ti alloys depending on welding conditions. In contrast, the fracture load of unwelded Ti, gold, or Co–Cr alloys in different configurations of laser welding were not achieved (Watanabe *et al.*, 2001, 2003, 2004, 2006). Especially for gold and Co–Cr alloys, only 50 per cent or less of the original measurements were found. In the study by Bertrand *et al.* (2004), a small change in the chemical composition of the Ni-based alloys caused an important difference in weldability.

Rocha *et al.* (2006) compared laser and TIG welding of non-precious alloys. TIG welding increased the flexural strength of Ti, Co–Cr, and Ni–Cr as the used welded cylinders presented higher flexural strength than the non-weld cylinders. The highest means were observed for Co–Cr weld by TIG and non-welded Co–Cr. By contrast, laser welding achieved only 17.5 per cent of the flexural strength of Co–Cr alloy. When joining Co–Cr alloy specimens, Zupancic *et al.* (2006) showed significant differences between brazing and laser welding. Those authors estimated a low penetration depth, peripheral overheating, porosities, and carbon content of the alloy as possible reasons for the relative weakness of laser welding.

The evaluation of three orthodontic arch wire alloy materials, stainless steel, beta titanium, and Timolium, for their laser-weld characteristics showed significantly different tensile strength values between these materials (Krishnan and Kumar, 2004). Although a comparison with original wires was not carried out in that study, it could be assumed that laser-welded specimens showed a significantly lower tensile strength than pure metals.

More recently Bock et al. (2008) showed that small changes in laser welding parameters significantly influenced the mechanical properties of orthodontic wires. Although laser welding is a solder-free alternative for orthodontic purposes, further investigations are needed to determine the optimal parameters.

3.7 Laser minor surgery

Laser surgery offers numerous advantages compared with traditional scalpel surgery. Soft-tissue excision is more precise with a laser than a scalpel (Rossman and Cobb 1995). A laser coagulates blood vessels, seals lymphatic, and sterilizes the wound during ablation, maintaining a clear and clean surgical field. The use of soft-tissue lasers result in a shorter operative time and faster postoperative recuperation (Sarver and Yanosky 2005). Laser surgery is routinely performed by using only topical anesthetic, which is particularly beneficial in an open orthodontic clinic (Sarver 2006). There is markedly less bleeding (particularly for frenal surgery), minimal swelling, and no need for irritating sutures or unsightly periodontal dressing (Haytac and Ozcelik 2006). Post surgically, patients report less discomfort and fewer functional complications (speaking and chewing), and require fewer analgesics than do patients treated with conventional scalpel surgery (Haytac and Ozcelik 2006).

The primary disadvantage of laser surgery is its high expense. Some clinicians have reported greater tactile sense with a scalpel (which might be particularly true for noncontact

soft-tissue lasers such as the erbium laser), tissue desiccation, and poor wound healing (Baker et al. 2002).

Lasers cut by thermal ablation—decomposition of tissue through an instantaneous process of absorption, melting, and vaporization. Essentially, the cells of the target tissue absorb the concentrated light energy, rapidly rise in temperature, and produce a micro-explosion known as spallation (Moritz 2006).

Surgical lasers typically have (1) a central zone of carbonization surrounded by, (2) a zone of vaporization, coagulation, and protein denaturation, and (3) a stimulating zone. This may be one reason for the improved healing with laser surgery compared with traditional scalpel surgery. During laser curettage, sufficient hemostasis and significant reduction of the initial levels of periodontal pathogens are achieved (Lioubavina-Hack 2002). Various applications of laser surgery in orthodontics are:

3.7.1 Gingival enlargements, gingival hyperplasia and reshaping gingival shape and contours

Sometimes removal of excessive gingival tissues is necessary to provide optimal display of teeth. For example, inadequate tooth display in smile in an adolescent patient may be related to altered passive eruption or gingival encroachment, making the teeth appears short. In this cases, gingivectomy may provide sufficient tooth display and appropriate tooth proportions.

Gingival hyperplasia is commonly observed during orthodontic treatment, especially in patients with poor oral hygiene. Generally, it is preferred to postpone treatment of gingival hyperplasia until the end of orthodontic treatment, unless the gingival tissue or enlargement interferes with tooth movement. If this occurs, the excess gingiva must be removed surgically during the treatment. Orthodontists should also consider gingival shape and contour of the teeth and make necessary corrections to provide optimal treatment results at the end of orthodontic treatment. Recontouring gingival shape and contour can be readily accomplished in the orthodontist's office with a diode laser. Laser gingivectomy has advantages such as minimal bleeding and postoperative pain and no swelling (Lioubavina-Hack 2002). Correction of gingival hyperplasia can also be performed easily with the aid of laser light.

3.7.2 Fibrotomy

Fibrotomy (Pericision) is frequently indicated to provide long term stability of teeth with severe rotations before treatment. This procedure is usually performed for upper and lower anterior teeth (e.g. maxillary lateral incisors in class II Div 2 patients) where maintaining treatment results is of great importance. Fibrotomy or severing of transpalatal fibers should be performed at the end of orthodontic treatment and before appliance removal.(Vanarsdall RL and Secchi AG, 2005) The teeth should be held in good alignment after fibrotomy when gingival healing occurs.

The poor patient acceptability in conventional fiberotomy, as an invasive procedure, suggests that an alternative technique needs to be considered. Kim et al. (2010) investigated the effectiveness and periodontal side effects of laser circumferential supracrestal fibrotomy (CSF) of orthodontically rotated teeth in beagles. A gallium-aluminum-arsenide (Ga-Al-As) diode laser with an 808-nm wavelength and 0.4-mm fiber diameter was used. The laser tip was inserted into the gingival sulcus to the level of the alveolar bone crest, and the incision

was extended around the tooth circumference with the system configured to the soft tissue cutting mode (continuous wave; 1.2 W). The amount of relapse, sulcus depth, and gingival recession were measured at weeks 4 and 8. They concluded that laser CSF is an effective procedure to decrease relapse after tooth rotation, causing no apparent damage to the supporting periodontal structures. It was claimed that the bactericidal effect transferred by the laser within the periodontal pocket can reduce the risk of infection.

3.7.3 Frenectomy

Frenectomy is usually indicated to prevent relapse after correction of midline diastema. Before eruption of maxillary canines, small physiologic spaces usually exist between maxillary incisors, a developmental stage named "ugly duckling stage". These spaces tend to close spontaneously after eruption of maxillary canines. Therefore frenectomy is not indicated during mixed dentition treatment, unless the presence of a large diastema between central incisors causes a great aesthetic problem, or prevents the eruption of other anterior teeth. When frenectomy is indicated, it is recommended to close the space between central incisors with orthodontic treatment prior to frenectomy. Otherwise, the formation of scar tissue prevents orthodontic space closure. Of course in some occasions, the presence of a very thick frenum may prevent space closure. If this occurs, frenectomy should be performed after partial space closure, and orthodontic treatment should be resumed immediately after frenectomy to complete space closure. In the conventional surgical method a simple incision is used to allow access to the interdental area, the fibrous connection to the bone is removed, and the frenum is then sutured at a higher level.

Olivi et al. (2010) clinically evaluated the efficacy of Er,Cr:YSGG laser at a power setting of 1.5 W or less in 156 frenectomies. The reported very high patient acceptance and no postoperative adverse events. Recently diode laser frenectomy without infiltrated anesthesia was suggested by Kafas et al. (2009). They concluded that this procedure have optimum healing post-surgically. However, in severe cases of soft tissue excision the need of anesthesia may be essential (Kato and Wijeyeweera 2007).

Haytac and Ozcelik (2006) reported that CO2 laser treatment used for frenectomy operations provides better patient perception in terms of postoperative pain and function than that obtained by the scalpel technique. They suggested that CO2 laser offers a safe, effective, acceptable, and impressive alternative for frenectomy operations. The results were the same for Nd:YAG laser frenectomy. Kara (2009) compared the effects of Nd:YAG laser and conventional technique on the degree of preoperative anxiety levels, postoperative pain, discomfort, and functional complications (eating and speech) of frenectomy. The results suggested that Nd:YAG laser treatment of soft tissue disorders provides better patient perceptions of success than those seen with conventional surgery.

4. Low intensity laser therapy in orthodontics

4.1 Description of therapeutic lasers

Low level laser therapy (LLLT) is also known as "soft laser therapy" and bio-stimulation. The use of LLLT in health care has been documented in the literature for more than three decades. Numerous research studies have demonstrated that LLLT is effective for some specific applications in dentistry. The LLLT literatures are large, with more than 1,000 papers published on this topic. A problem in dissecting this literature is the variation in methodology and dosimetry between different studies. Not only have a range of different

wave lengths been examined, but exposure times and the frequency of treatments also vary (Walsh et al,2006).

While broad band light can exert effects on cells, interest has been concentrated on using lasers as a light source because of their greater therapeutic effect (Karu. 1989, Laakso et al. 1993). While much of the initial work with LLLT used the helium – neon gas laser work with LLLT used the helium- neon gas laser (λ = 632.8 nm), nowadays most LLLT clinical procedures are undertaken using semiconductor diode lasers, for example, gallium arsenide based diode lasers operating at λ = 830 nm or λ = 635 nm wavelengths . Since wavelength is the most important factor in any type of phototherapy, the clinician must consider which wavelengths are capable of producing the desired effects within living tissues. The typical power output for a low level laser device used for this therapy is of the order of 10-50 mW, and total irradiances at any point are of the order of several Joules. Thermal effects of LLLT on dental tissues are not significant, and do not contribute to the therapeutic effects seen. The wavelengths use for LLLT has poor absorption in water, and thus penetrate soft and hard tissues from 3 mm to up to 15 mm (Sandford &Walsh.1994;Ohshiro & Calderhead.1998; Walsh.2003;Walsh et al.2006).

4.2 History

In 1967, a few years after the first working laser was invented, Endre Mester in Semmelweis University, Budapest, Hungary wanted to test if laser radiation might cause cancer in mice (Mester, 1968). They did not get cancer, and to his surprise the hair on the treated group grew back more quickly than the untreated group. This was the first demonstration of "laser biostimulation". In fact, light therapy is one of the oldest therapeutic methods used by humans historically as solar therapy by Egyptians, later as UV therapy for which Nils Finsen won the Nobel Prize in 1904. (Roelandts,2002).

The use of lasers and LEDs as light sources was the next step in the technological development of light therapy, which is now applied to many thousands of people worldwide each day. The reason why the technique is termed LOW-level is that the optimum levels of energy density delivered are low when compared to other forms of laser therapy as practiced for ablation, cutting, and thermally coagulating tissue. In general, the power densities used for LLLT are lower than those needed to produce heating of tissue, i.e., less than 100 mW/cm2, depending on wavelength and tissue type (Huang YY et al., 2009).

4.3 Introduction

Although laser phototherapy (“low level laser therapy”) has been practiced for more than 30 years there is still controversy regarding its scientific standard. Questions still remain even though more than 400 studies with a dental focus have been reported. The biomodulative effects exerted on cells are well documented (Karu 2003, 2006, 2007), to a certain degree in animal studies. The safety of the treatment is also well documented. In spite of clinical observations for a great variety of conditions, some controversy remains.

Due to the fact that so many parameters are included, it is more difficult to reach a consensus in this area of dental laser applications than in the domain of high-intensity laser applications. Many different wavelengths, power densities, energy densities and application modes have been used and there is no current consensus about optical standards. In addition, the reporting of the actual laser parameters and dosimetry in studies is often substandard and control studies are therefore difficult to perform. Consequently the

evaluation of the various applications becomes problematic. The optical properties and performance of the various commercially available lasers vary widely, adding to the problems in the evaluation process (Bradley & Tuner, 2007).

Surgical lasers are rather precise in their indications: the results are verified more easily with the naked eye as well as through subsequent lab analyses. Therapeutic lasers work on the cellular level, influencing the fundamental functions of the cells. Any pathological condition can thus theoretically be improved if the suitable wavelength and energy of light is applied. This is at the same time the beauty and the problem of laser biomodulation: how can one therapy be applied in so many situations? There is supposedly no universal method in the history of medicine and a skeptical attitude from dentists is basically a sound reaction. The results of non-dental research often have to be extrapolated into dental area when conclusions are to be attempted. It should to a high degree of probability be possible to extrapolate the effects on nerves, wound healing, pain relief, edema, etc., and in non- dental areas of the animal or human body for dental conditions. A problematic part of the existing literature is the frequent lack of understanding of laser physics and laser therapeutic approaches, whether from manufacturers, users, researchers or indeed from peer reviewers(Bradley & Tuner, 2007).

Several meta-analyses have failed to evaluate crucial dosimetric parameters such as applied energies and energy densities, and later re-evaluations using the same material have been able to turn a negative interpretation into positive on (Bjordal et al. 1998, 2001, 2003). But once published , meta analyses are irrepressible. Even Cochrane analyses of laser interventions (Bjordal 2005) have failed to observe basic analysis of doses, wavelengths and application modes. Future studies had better address the most crucial parameter of the study, namely the laser itself. Consensus is needed on how to describe these parameters.

The phenomenon of cell biomodulation is well described (Karu 2003), but the optimal clinical parameters are still little known and will have to be more accurately defined in future studies. Many positive studies were conducted within a supposed "therapeutic window" but were not necessarily close to the optimal applications. The most important fields of future research will be discussed here. Laser phototherapy is non- invasive, non-pharmaceutical, has very few side effects, is painless and enjoys a high acceptance from patients. More attention to the method's potential is therefore logical .A not so well-known fact that should be recognized, is that surgical lasers can have a biomodulatory effect, too. Furthermore, all these "surgical" lasers can be used for biomodulation purposes if the dosage is adjusted accordingly. To further emphasize this fact would increase the value of a surgical laser (Bradley & Tuner, 2007).

4.4 Mechanism of action

The mechanisms of low level laser therapy are complex, but essentially rely upon the absorption of particular visible red and near-infrared wavelengths in photoreceptors within sub-cellular components, particularly the electron transport (respiratory) chain within the membranes of mitochondria(Karu.1989a,1989b; Walsh et al,2006).

The absorption of light by the respiratory chain components causes a short- term activation of the respiratory chain, and oxidation of the NADH pool. This stimulation of oxidative phosphorylation leads to changes in the redox status of both the mitochondria and the cytoplasm of the cell. The electron transport chain is able to provide increased levels of promotive force to the cell, through increased supply of ATP, as well as an increase in the

electrical potential of the mitochondria membrane, alkalization of the cytoplasm, and activation of nucleic acid synthesis. Because ATP is the "energy currency" for a cell, LLLT has a potent that results in simulation of the normal functions of the cell(Yu et al.1997;Walsh et al, 2006).

Karu.(1987,1988,1989)who has studied the bio-stimulative effects of light on cell cultures in great detail, has demonstrated that cell cultures that are initially irradiated with laser light show a range of biological effects. Of importance, is these cultures are then irradiated with non- monochromatic and incoherent light, the previous laser- produced biological effects are almost nullified. This suggests that there are more complex mechanisms at work than the simple excitation of polarization- sensitive chromophores in the cell. Considerable insight into the effect of wave length on LLLT has been gained from the work of Karu who over a period of years has conducted extensive research using cell cultures of various types. Her work has provided and action spectrum for bio-stimulation of the rate of DNA synthesis in HeLa cells, and for proliferation of bacteria and yeast colonies. These spectra show peaks in the blue (λ = 404 nm and λ = 454 nm), red (λ = 620nm), and near-infrared (λ =760 nm) and λ = 830 nm). (Karu,1987,1988,1989).The tissue response to photonic energy as well as to other energetic stimuli follows the Arndt Schultz pattern where low energies stimulated and high energies tend to inhibit.(Fig.5). It follows from this that low energies will be appropriate for the stimulation of healing while high energies may be more suitable for pain control with the aim of suppressing aberrant sensitization of nerve fibers(Bradley & Tuner, 2007).The Arndt-Schulz law thus provides a useful theoretical basis to explain the varying photobiostimulatory and photobioinhibitory effects observed in the laboratory; however it also goes some way to accounting for the apparently conflicting results that are sometimes achieved with low-intensity laser therapy. (Fig.5)

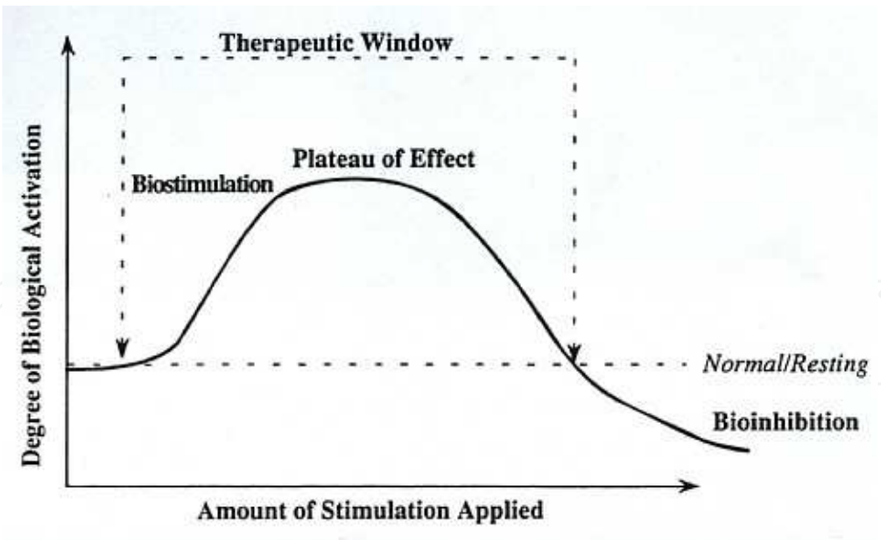


Fig. 5. Arndt-Schultz Law

This is only a generalization in that promotion of healing in an inflammatory situation may have a pain relieving action in its own right. From an extensive background of laboratory date, Dyson. (2005) has divided cellular responses in the context of healing into primary and secondary responses.

Primary responses:

1. The photons are absorbed by cytochromes.2. Singlet oxygen free radicals are generated, effecting ATP synthesis and thus increasing the energy available to the cells.3. Nitric oxide is produced.4. Reversible increase in cell membrane permeability to calcium and other ions occurs, triggering changes in cell activity, i.e. secondary responses.

Secondary responses:

1. DNA and RNA synthesis.2. Cell proliferation.3. Growth factor release.4. Collagen synthesis by fibroblasts.5. Changes in nerve conduction, neurotransmitter release etc.

Potential mechanisms of pain relief:

The potential mechanisms involved in pain relief (Bradley, 2005) have been postulated as:

a. Direct action on nerve. There is evidence from the animal experimental field using excised rat sciatic nerve that 830 nm irradiation with an incident power of 60 mw for 60 seconds (4 Jules per point) and 120 seconds (8 Joules per point) can inhibit the activity of sodium potassium ATP -ase responsible for never depolarization in generation of the action potential (Kudoh et al, 1989). This effect is likely to he maximal for the small diameter C fibers responsible for most chronic pain, due to their lack of a protective myelin sheath.
b. Energization of inactivated enzymes: Enzymes may be inactivated by such factors as hypoxia and acidosis in areas of muscle spasm with ischemia (e.g. trigger points) or in foci of chronic inflammation. There is evidence that laser energy can reactivate these enzymes (Bolognani & Volpi, 1992). Free radicals for example may be a source of pain in dysfunctional muscle where the enzyme super oxide dismutase (SOD) can break down these entities if reactivated.
c. Production of Energy Molecules (ATP) in Dysfunctional Muscle. The interaction of myosin and actin in muscle requires adenosine triphosphate (ATP) and its lack may contribute to painful dysfunction. A characteristic of the response of cells to laser light is the formation of ATP (Krau, 2000).
d. Reduction of prostaglandin levels. There is evidence from the clinical and cell culture work that laser exposure can reduce levels of the algogenic substance PGE2 (Mizutani et al., 2002).

4.5 Contraindication

Absolute contraindications to LPT are not known, but there are several relative contradictions and caveats. Areas of malignancies or suspected malignancies should be avoided at present due to insufficient knowledge. For the same reason irradiation of patients with coagulation disorders and photosensitivity should be avoided. Irradiation over the thyroid has been reported as a contraindication, but current knowledge does not substantiate such risk when irradiation is performed in or close to this area on healthy individuals. However, care is recommended in cases of hyperthyroidism. Pregnancy is reported as a caveat, but this would only apply in case of large doses over the abdomen. As for epilepsy, there are anecdotal reports on seizure attacks triggered by pulsed light, but it would probably have to be in the visible range and observed by the patient. Irradiations over testicles and diabetic wounds have been reported as contraindications for LPT, given the correct diagnosis. Some articles mention patients wearing pacemakers as a contraindication, but this is likely a misunderstanding (Bradley & Tuner, 2007).

4.6 Conclusions

Low level laser therapy has been found to accelerated wound healing and reduce pain, possibly by stimulating oxidative phosphorylation in mitochondria and modulating inflammatory responses. By influencing the biological function of a variety of cell types, it is able to exert a rage of several beneficial effects upon inflammation and healing (Walsh et al,, 2006). LLLT exerts marked effects upon cell in all phases on wound healing, but particularly so during the proliferative phase. There is good evidence that the enhanced cell metabolic functions seen after LLLT are the result of activation of photo-receptors within the electron transport chain of mitochondria. The effects specific for wavelength, and cannot be gained efficiently with normal, non- coherent, non- polarized light sources, such as LEDs(Walsh et al.,2006).

Future trials of new LLLT applications in dentistry should make use of standardized, validated outcomes, and should explore how the effectiveness of the LLLT protocol used may be influenced by wavelength, treatment duration, dosage, and the site of application.

4.7 Photobiomodolation effects of lasers in orthodontics

4.7.1 Pain reduction

Pain or discomfort is a common experience during fixed orthodontic treatment. Pain is usually appears several hours after orthodontic force application and slowly increases until 24 hours, then it returns to the basic level at approximately 5th days. This pain cycle may be repeated after each appointment, although for nearly all patients, it is the most severe after initial arch wire placement. For patients, pain may be the most important side effect of orthodontic treatment and one of the main reasons for their lack of compliance or missing appointments.(Sergl et al., 1998; Turhani et al., 2006; Young et al., 2006; Bird et al., 2007; Polat et al., 2005) Furthermore, nearly all orthodontic patients report pain during chewing and biting and this can oblige them to change diet habits. Finally, it has been demonstrated that pain and discomfort during orthodontic treatment negatively affects the satisfaction of patient from aesthetic results of orthodontic treatment.(Al-Omiri and Abu Alhaija, 2006) If orthodontists are able to prevent or control pain, patients may have a better quality of life and show more tendencies to cooperate with treatment recommendations.

The mechanism through which orthodontic forces produce pain has not well recognized, but there is some evidence indicating that pain is related to the change in blood circulation of periodontal ligament, causing ischemic areas in the PDL. For this reason, a heavier force may cause a greater degree of pain due to the formation of larger ischemic areas in the periodontal ligament. Pain is also dependant to the formation of metabolic products such as prostaglandins and substance P which stimulate pain receptors.

To relieve pain, most orthodontists recommend their patients to use nonsteroidal antiinflammatory drugs (NSAIDs), to inhibit the formation of pain producing agents such as prostaglandins and thus reduce the pain. However, these drugs may have side effects and therefore are contraindicated in some patients. Furthermore, most drugs used for pain control can have negative effects on tooth movement if used chronically, due to their inhibitory effects on prostaglandins.

Considering the side effects of analgesics, researchers have looked for other new, but safer approaches, such as LLLT to reduce pain from orthodontic procedures (Xiaoting 2010). Although only a few studies have dealt with the response of orthodontic patients to LLLT, all concluded that LLLT reduces pain during orthodontic treatment (Lim et al. 1995, Katoh et al. 1997, Harazaki et al. 1997, Harazaki and Isshiki 1998, Turhani et al. 2006, Youssef et al

2008). Lim et al. (1995) observed in orthodontic patients that pain for teeth irradiated with a gallium-arsenic-aluminum diode laser was lower compared with pain when a placebo was used. Harazaki and Isshiki (1998), on irradiating both vestibular and lingual sides of teeth with an orthodontic appliance, using a helium-neon laser with a 632.8-nm wavelength, operated at 6 mW for 30 seconds, reported that the laser therapy not only reduced patient discomfort but also delayed the onset of pain. Data have shown the efficacy of LLLT for pain control after placement of the first archwire (Turhani et al. 2006, Tortamano et al. 2009). In a study by Tortamano et al. (2009) the patients in the experimental group received gallium-arsenic-aluminum diode laser irradiation with a wavelength of 830 nm. The laser beam emitted a constant wave with a mean output of 30 mW. Each tooth received a dose of 2.5 J per square centimenter on each side (buccal and lingual). The patients in the LLLT group had reduced pain duration and a lower intensity of pain. Although these authors couldn't find any effect on the start of pain perception, previous studies showed delayed pain onset in patients who had LLLT (Harazaki 1997, Turhani 2006).

Overall, based on the efficacy of LLLT to control pain in orthodontic treatment, LLLT could be recommended for pain control during fixed orthodontic appliance therapy. The reason for reducing its clinical use seems to be the total time (32–37.5 minutes) for application to both dental arches (Lim et al. 1995, Katoh et al. 1997, Harazaki et al. 1997, Harazaki & Isshiki 1998, Tortamano et al. 2009). Yet many diverse opinions existed concerning the duration of treatment, radiant power, frequency, and energy density.

4.7.2 Tooth movement

The biological control of tooth movement still has not well recognized. The most accepted theory of tooth movement is pressure-tension theory, which is based on stimulating cellular differentiation through chemical mediators. This theory states that force application causes tooth displacement within the PDL, which in turn results in compression in some areas of the PDL, while other parts may be stretched. In the compression side blood circulation is decreased, while in the tension side blood flow is maintained or even increased. The alteration in blood flow creates rapid changes in the proportion of oxygen and other metabolites within the PDL, which in turn can stimulate the release of other biologically active elements. These chemical alterations would stimulate cellular differentiation and cell activity.(Proffit et al., 2007) Prostaglandin E, Interleukin 1α and Interleukin 1β are some of the important mediators released during the process of tooth movement. It is believed that orthodontic tooth movement includes many inflammation like reactions, because it is associated with high vascular activity, release of many leukocytes and macrophages, and involvement of the immune systems. This is important because it implies that the whole cascade of factors involved in an inflammation process may be part of the reactions to orthodontic forces in the tooth-supporting tissues.(Thilander et al., 2005)

Several studies have represented the effects of LLLT on orthodontic tooth movement. In five of nine animal studies about stimulation effects of LLLT on orthodontic tooth movement (Kawasaki and Shimizu 2000, Sun et al. 2001, Goulart et al. 2006, Yamaguchi M et al. 2007, Seifi et al. 2007, Fujita et al. 2008, Yoshida et al. 2009, Yamaguchi et al. 2010, Kim et al. 2010), experiments were performed on albino Wistar rats using the same laser device and the same parameters (Kawasaki and Shimizu 2000, Yamaguchi M et al. 2007, Fujita et al. 2008, Yoshida et al. 2009, Yamaguchi et al. 2010). Even though the energy density used in these studies was considerably higher (54 J, 19.108 J/cm2) than it is thought to be appropriate for

biostimulation (2–12 J/cm2), it was concluded in all of the five studies that laser radiation had stimulated tooth movement. When the other animal studies were examined, it was noticed that there were differences about subject type, the energy dose given, and about the results. Seifi et al. (2007) reported the effects of two types of LLL wavelengths (850 nm and 630 nm) on orthodontic tooth movements in rabbits. The total amount of energy in 850 nm and 630 nm laser groups was 8.1 J/cm2 and 27 J/cm2, respectively. The authors showed that the amount of orthodontic tooth movement, after LLL application, was diminished, and there was no significant difference between the laser groups. Cruz et al. (2004), Youssef et al. (2008), and da Silva Sousa et al. (2011) demonstrated clinically that LLLT accelerates the orthodontic movement in humans. Cruz et al. (2004) conducted an experiment on 11 young patients who required tooth movement for extraction space closure. They were irradiated with LLLT of 780 nm wavelength (for 10 s at 20 mW; 5 J/cm2) on one side of the maxilla for 4 days in a month and were not irradiated on the opposite side, which acted as the control. The results showed that the experimental side demonstrated significantly more rapid progression of space closure than the control side. Youssef et al. (2008) evaluate the effect of the GaAlAs diode laser (809 nm, 100 mW) during an orthodontic movement in a group of 15 adult patients. They demonstrated that the velocity of canine movement was significantly greater in the lased group than in the control group. This was confirmed by da Silva Sousa et al. (2011) which used a diode laser (780 nm, 20 mW, 10 sec, 5 J/cm2) for 3 days. However, Limpanichkul et al. (2006) found no difference in tooth movement rate after application of LLL for 3 days in a month. They claimed that the energy capacity of LLL (25 J/cm2) in their study was probably too low to produce stimulatory effects on orthodontic tooth movement. However, their LLL application method for orthodontic tooth movement was different from the others. They used a 0.09 cm2 spectral area to irradiate the alveolar mucosa at some point. This restricted application might be a lack for the whole periodontium surrounding the tooth.

Fujita et al. (2008) and Yamaguchi et al. (2007) reported that LLLT stimulated the velocity of tooth movement via RANK and c-Fms gene expressions *in vitro*. This was confirmed by Yamaguchi et al. (2010) which showed that LLLT accelerates the process of bone remodeling by stimulating MMP-9, cathepsin K, and integrin subunits of a(v)b3 expression during orthodontic tooth movement in rats.

4.7.3 Distraction osteogenesis

Distraction osteogenesis is a method to induce new bone formation and investing soft tissue under the influence of tensional stress at osteotomized sites of a healing bone. Distraction osteogenesis not only induces bone formation but also results in formation of new soft tissue (histogenesis) over the new bone. This method was used successfully by Alizarow in the 1950s to lengthen the bony segments of the limbs, and now is widely used in dentistry for correcting deficient growth of the maxilla and mandible in patients with congenital problems such as cleft lip/palate and hemifacial microsomia. Distraction osteogenesis makes it possible to achieve a greater amount of bone lengthening than that achieved with conventional orthognathic surgery without the need for placing bone grafts. An additional advantage of this technique is that the correction can be performed at an earlier age. However, precise positioning of the jaw is not possible with this method, and consequently orthognathic surgery may be required later to achieve optimal treatment results. Distraction osteogenesis is a suitable option for extensive lengthening of the ramus in patients with

moderately severe hemifacial microsomia, and also for advancing the mid face in patients having severe maxillary deficiency such as those with Crouzon syndrome. Furthermore, it is now possible to widen mandibular symphysis through distraction osteogenesis technique, a procedure that cannot be performed with orthognathic surgery due to the lack of soft tissue for covering the bone graft at that area.

Distraction osteogenesis consist of four sequential steps:(Cope and Samchukov, 2005) The first step is osteotomy, which provokes the process of bone repair at surgically created sites. The second stage is called latency, which defines the period between bone fracture and initiation of tensional stress to the bone. In latency period, a reparative callus is allowed to form. In the third stage or distraction phase, a gradual traction is applied to the bone to create new bone at the surgical sites. The bony segments are usually separated at a rate of 0.5-1.5 mm per day during the distraction phase. Consolidation is the fourth step of distraction osteogenesis defining the period between the end of traction application and removal of the distraction device. This stage is necessary to allow complete mineralization of the new bone formed by distraction process. Because of the time required for bone maturation and for removal of the distracter, distraction osteogenesis may generate discomfort, which has led some authors to study solutions to accelerate new bone formation (Hübler et al. 2010).

Miloro et al. (2007) evaluated the effect of LLLT during mandibular distraction osteogenesis and concluded that LLL accelerates the process of bone regeneration during the consolidation phase after distraction osteogenesis. Further, Kreisner et al. (2010) evaluated the action of LLLT on the percentage of newly formed bone in rabbit mandibles that underwent distraction osteogenesis. Infrared GaAlAs LLLT (λ=830 nm, P=40 mW) was applied directly on the bone site that underwent distraction osteogenesis during bone consolidation at 48-hour intervals. The results suggested that the percentage of newly formed bone was greater in the LLLT group than in the control group. Cerqueira et al. (2007) stated that the laser has been more favorable when used in the consolidation period, after bone elongation. The results of a study by Hübler et al. (2010) showed that LLLT had a positive effect on the percentage of newly formed bone, on the chemical composition according to the Ca-to-P ratios, and on the crystallinity and crystalline structure at the distraction osteogenesis sites.

4.7.4 Retention & relapse

Relapse after orthodontic correction of malocclusions is an undesirable but frequent experience for nearly all orthodontists. Teeth that have moved by orthodontic forces tend to return to their original positions, a phenomenon referred to as relapse. Generally, occlusion instability occurs because of the following reasons:

1. Changes related to growth: This type of relapse appears in long time and is usually related to continuation of growth in the original pattern caused malocclusion. An example is deepening of overbite due to growth or uncoordinated growth of maxilla and mandible in orthodontically treated patients. To counteract these changes, active treatment should be continued until growth is essentially complete.
2. Inherent instability of the occlusion due to soft tissue pressure: Alignment of the teeth in the dental arch is in equilibrium between the tongue pressure and labial/buccal soft tissue pressure. If there is any major imbalance between extra and intra oral soft tissue pressures, there would be a relapse tendency. For example widening of the mandibular

arch, particularly in the canine area, is susceptible to relapse. The only solution to counteract relapse in these cases is to use permanent retention.

3. The changes related to fibrous system of PDL and gingival: These fibers may be responsible for most of the short term relapse after orthodontic treatment, for example after correction of rotated teeth and diastema closure. The elastic fibers of the gingival in particular may be stretched and displaced for long times after orthodontic correction, causing tooth movement forces even one year after appliance removal.

After appliance removal, the important stage of retention period is initiated. In this period, the orthodontist aims to retain the corrected tooth position passively, while the alveolar bone and gingival and periodontal fibers are remodeled. During the period of retention, the osteoid is replaced by bundle bone, which is finally changed to lamellated bone with harvesian system, and gingival and periodontal fibers are also reorganized.

LLLT effects on the relapse tendency of orthodontically rotated teeth have not been fully characterized. Kim et al. (2010) investigated the effectiveness of LLLT on orthodontically rotated teeth in beagles. A Ga-Al-As diode laser was used. The biostimulation mode (pulsed wave, 10 Hz, 763 mW, 4.63–6.47 J/cm2) was used for irradiation, with the fiber tip held 2–3 mm away from the gingiva. The coronal and apical thirds of the roots were irradiated every 3 days for 30 seconds each for 4 weeks. They concluded that LLLT of orthodontically rotated teeth without retainers increased the rotational relapse of the teeth compared with the control group.

4.7.5 Growth modification

Maxillary expansion

Maxillary expansion may be required in patients who have deficient maxillary width. This treatment also helps to remove crowding and align the teeth. The mid-palatal suture is separated easily up to age nine or ten, therefore any expansion device is expected to produce a combination of dental and skeletal expansion. However, the midpalatal suture tend to interdigitate more and more with increasing age, and heavy forces are needed to microfracture it in adolescent patients. Usually a fixed type of jackscrew device is used to apply heavy forces to separate the suture, and either slow or rapid expansion protocols can be used for this purpose.

Saito and Shimizu (1997) studied the effects of LLLT on the expansion of midpalatal sutures in rats, comparing the bone regeneration obtained with and without laser treatment. Their results showed that the therapeutic effects of laser are dependent on the total dosage, the frequency, and the duration of the treatment. Their laser-irradiated group showed 20-40% better results when compared to the control group.

Mandibular growth

When mandible is deficient as is seen in most class II patients, growth modification is a suitable treatment option for growing children. To do this, a functional appliance is usually indicated to pull the condyle out of the glenoid fossa a sufficient distance for long durations, enhancing condylar growth amount and creating a more favorable growth direction in mandibular condyle. Growth modification for correcting mandibular deficiency can be performed successfully in late mixed dentition and early permanent dentition patients before the end of the adolescent growth spurt, but the chance of skeletal versus dental correction is reduced as the patient gets older.

It was proposed that if LLLT increases bone and cartilage formation, the treatment might be easier and more stable. In 2010 Seifi et al. investigated the effects of low level GaAs diode laser (λ=904 nm, 2,000 Hz, pulse length 200 ns and output power 4 mW) on chondroblastic and osteoblastic activity of condyles in rats. Laser irradiation was performed either bilaterally or on the right condyle. They showed that LLLT had a significant effect on the increase of mandibular length in rats and might be helpful in the correction of class II malocclusions. However, further studies are required to confirm these results.

5. Conclusion

To have a precise diagnosis and to select a proper and successful laser-assisted treatment modality for a disease, the clinician should have a comprehensive understanding of the principles and fundamentals of laser and its helpful abilities.When considering the use of lasers in clinical dentistry, the practitioner must use clinical experience, receive proper training, and have familiarity with the operating characteristics of each device. Because of the variable composition of human tissue and the differing ways in which laser energies are absorbed, no single laser is appropriate for all dental applications.

6. References

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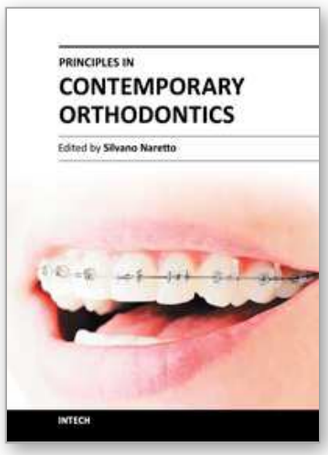
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Principles in Contemporary Orthodontics
Edited by Dr. Silvano Naretto

ISBN 978-953-307-687-4
Hard cover, 584 pages
Publisher InTech
Published online 25, November, 2011
Published in print edition November, 2011

Orthodontics is a fast developing science as well as the field of medicine in general. The attempt of this book is to propose new possibilities and new ways of thinking about Orthodontics beside the ones presented in established and outstanding publications available elsewhere. Some of the presented chapters transmit basic information, other clinical experiences and further offer even a window to the future. In the hands of the reader this book could provide an useful tool for the exploration of the application of information, knowledge and belief to some orthodontic topics and questions.

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Fekrazad Reza, Kalhori A.M. Katayoun, Ahrari Farzaneh and Tadayon Nikoo (2011). Laser in Orthodontics, Principles in Contemporary Orthodontics, Dr. Silvano Naretto (Ed.), ISBN: 978-953-307-687-4, InTech, Available from: http://www.intechopen.com/books/principles-in-contemporary-orthodontics/laser-in-orthodontics

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