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The laser revolution: An auroral glow of contemporary implant dentistry

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Abstract
Statement of problem: The parallels in the expansion of implant dentistry and laser science are apparent. As advocates for laser dentistry continue to seek new ways to use the technology and as more practitioners become involved in implant dentistry, it is logical to see the concurrent use of both technologies in clinical practice. However, the use of lasers in implantology has often prompted controversy, due either to the essential photo-thermal action of high powered lasers or to the risks associated with 'blind' techniques.
Objective: To evaluate and de-mystify the basis of a wide variety of applications of various laser systems used in surgical as well as non-surgical phases of implant dentistry.
Method of study: A Medline search was completed for various applications of different laser wavelengths as related to implantology. Our review evaluated *in vitro* examinations, clinical experience and long-term clinical studies.
Results and conclusion: The exact selection of the appropriate laser system and wavelength is dependent on laser-tissue interactions. The scientific evaluation of recent literature warrants the use of CO_2 lasers primarily for soft tissue lasing with a special emphasis on Er:Cr:YSGG laser belonging to the erbium family and diode family in contemporary implant practice.
Clinical Relevance: This report describes the state-of-the-art application of different laser systems in modern implant dentistry including the path-breaking development as a bio-stimulant.

Keywords: Dental implant, laser, Nd:YAG, diode, CO_2, bio-stimulation

1. Introduction
Dentistry has changed tremendously over the past decade to the benefit of both the clinician and the patient. New materials and technologies have improved the efficiency and predictability of treatment for clinicians. Dentistry in the high tech era has been a witness to numerous technological innovations such as RVG, implants, CAD-CAM units and more recently lasers, all of which, have immensely enhanced planning and imparting proper dental care.
The concept of gentle surgical placement of a replacement device made of highly biocompatible metal titanium has stood the test of time. Concurrently, first introduced into the medical field in the 1960s, laser science has progressed in leaps and bounds with recent systems being indicated for a wide variety of dental procedures.
The words 'laser' and 'implants', conjures in the mind's eye varied facets of what might be described as 'modern' life. The words 'powerful', 'precise' and 'innovative' complement our conception of this world in terms of technology, whereas patients often associate the words 'magical' and 'lightening quick' with the use of lasers in contemporary practice. Nonetheless, in implant dentistry the use of laser is considered adjunctive in delivering a stage of tissue management conducive to achieving a completed hard or soft tissue procedure. Considerable research in this regard carried out to validate the innovative use of lasers has yielded mixed results. Certainly, however, today's lasers offer an opportunity to deliver hard and soft tissue treatments that, at least in outline, make the patient experience somewhat easier [2].
The present review is an attempt to appraise the readers of a plethora of clinical applications of dental lasers in the field of implantology as presented in the literature.

2. The concept of lasers put into practice
Essentially, the adjunctive use of surgical lasers in implant dentistry has sought to address efficient cutting of osseous hard tissue, haemostatic ablation of soft tissue and also the

sterilising effect through bacterial elimination. Less powerful, non-surgical lasers have been shown to modify cellular activity and enhance biochemical pathways associated with tissue healing. The decision to include lasers in everyday dental care depends not least upon financial considerations, but on laser-tissue interaction, therefore indirectly on the wavelength selected [2].

The word '*Laser'* is an acronym for *Light Amplification by Stimulated Emission of Radiation*. The energy generated by the laser is in or close to the optical portion of the electromagnetic spectrum and thus non-ionizing which does not produce untoward effects. Energy generated is amplified to extremely high intensity by an atomic process called stimulated emission. Since the emission energy is unique relative to its source and of known measurable quantity, the light will be of a single wavelength (monochromatic). The high-energy, single wavelength light is produced in a spatially stable form (collimated or non-divergent), with successive waveforms that are in phase (coherent). In consequence, the coherence and collimation of the light results in high energy density and the monochromatic wavelength will define specific target absorption. With respect to the monochromatic nature of laser light, a number of emission wavelengths have been developed that, for the purposes of current clinical dentistry, span the visible to the far infrared portions of the electromagnetic spectrum approximately 400-10,600 nm (Figure 1).

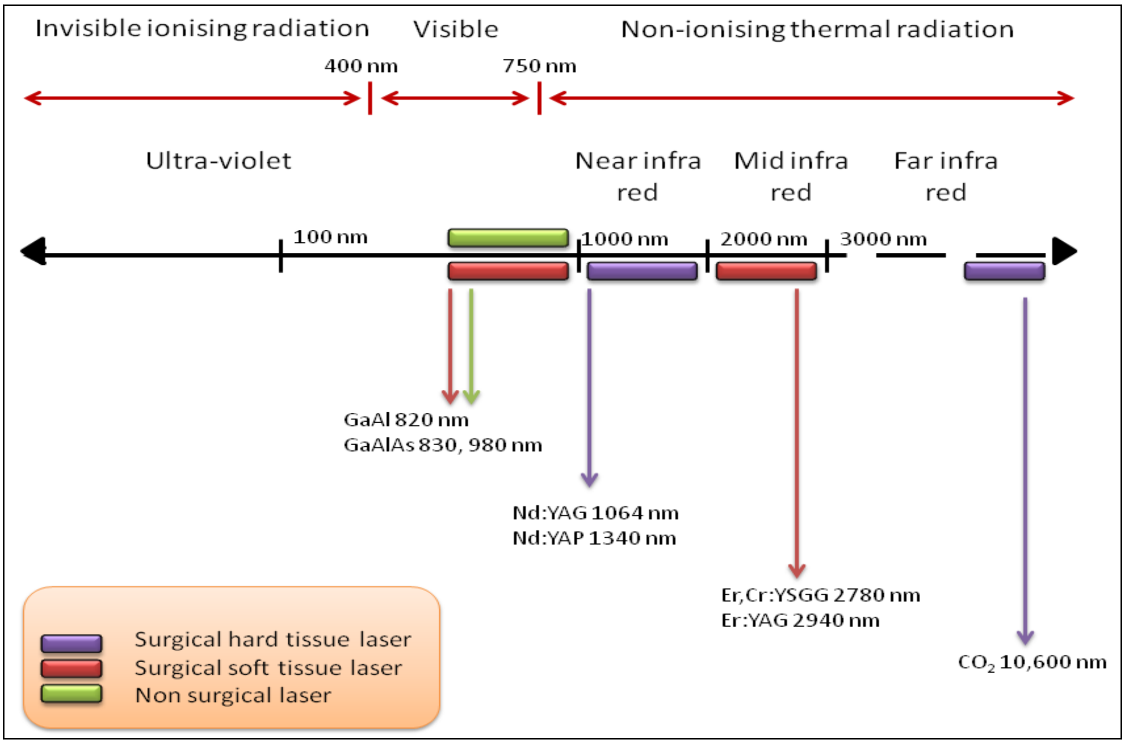

Fig 1: Figure describes various laser systems and their corresponding wavelength with reference to electromagnetic spectrum.

The CO_2, Nd:YAG, diode, argon and holomium wavelengths were introduced primarily to lase soft tissues. However, the introduction of erbium family of wavelengths, with its ability to safely remove hard tissue, has stimulated a new wave of interest in laser therapy in the dental profession. Thus, the parallel in the expansion of implant dentistry and laser dentistry in clinical practice is overwhelmingly apparent.

3. Significance of use of laser technology in implant dentistry

Merits of using lasers in implant dentistry are the same as for any soft tissue dental procedure. These include increased hemostasis thereby improving visibility [3], minimal damage to the surrounding tissue, reduced swelling, reduced infection and diminished post-operative pain [4]. Moreover, the increasing popularity of the erbium family of lasers, with their hard tissue ablation capability, has further extended the spectrum of indications for laser technology in implantology.

4. Application of lasers in modern day implantology

Lasers can be applied to almost any clinical situation, but their efficacy *versus* conventional techniques in many cases is unknown, with the exception of anecdotal reports [2]. The wide range of clinical application [5] of lasers can be broadly categorised into two modalities, namely, surgical use and non-surgical use.

4.1 Surgical use of lasers

Surgical lasers can be used in a variety of ways with regard to implantology, ranging from placement, second stage recovery and gingival management, through the treatment of peri-implantitis. Within this range of usage, dependant on wavelength employed, exists the ablation of target tissue and the ability to reduce bacterial contamination [6]. Although accepted by the dental community, there is no evidence-based advocacy [6] as to the use of any laser wavelength in producing a fully-prepared osteotomy site for the placement of root-form dental implants. However, there are communicatory reports [6] of the use of erbium YAG and erbium YSGG lasers to establish a controlled incision of overlying gingival tissue and to initiate a breach of the cortical bone plate, prior to the use of conventional implant drills. Such techniques, although inherently correctly based on documented laser-tissue interaction, run the risk of scepticism amongst practitioners more allied to a conventional surgical approach to implant placement thereby leading to controversy surrounding their use.

4.1.1 The fundamental controversy- Myth or reality

The fundamental key to success in implant placement is the apposition of normal healing bone onto the implant surface. The preparation of the osteotomy site demands a technique whereby the local temperature does not exceed 47 °C [6, 7]. However, it is a well-known fact that prime laser-tissue interaction results in the conversion of incident electromagnetic energy into heat energy. Consequently, any therapeutic use of lasers in implant dentistry must address this fact. Also, the possibility of surface damage of an existing fixture arising from incident laser light must be borne in mind.

The amount of thermal energy generated is a factor of numerous variables including absorption characteristics of a specified wavelength[4]. The first dental laser, the Nd:YAG (1,064 nm) offered advantages of soft tissue ablation, haemostasis and bacterial control [6]. Research into the use of this laser by Walsh *et al.* [8], Block *et al.* [9], Chu *et al.* [10] and others [11, 12, 13] drew conclusions that penetrating and high peak heat energy produced transmission of heat to the bone from the heated implant surface, potential for pitting and melting, and the porosity of the implant surface.

With the further development of other laser wavelengths, investigations were carried out with regard to the aforementioned observation. The general parameters of such studies included the emission mode of the laser, the material used in implant manufacture, its reflectivity and the conductive effects of heat through the implant into surrounding bone [6]. Titanium as a metal exhibits reflectivity to incident light energy which is lowest in the range 780-900 nm, rising as the wavelength increases towards 10,600 nm. Thus, the use of the CO_2 wavelength minimizes the risk of resultant temperature-induced tissue damage [4, 6]. An investigation in this regard by Mouhyi *et al.* [14] demonstrated that a CO_2 laser on a wet implant surface in pulsed mode at 8W(10 milliseconds pulse duration, 20 Hz for 5 seconds) induced a temperature increase of less than 3^0 C, well within the 10^0 C safety margin from 37^0 C to 47^0 C. However, Walsh *et al.* [8] documented thermal ill-effects of CO_2 laser on osseous structures limiting its use in hard tissue procedures. Nonetheless, excellent hemostatic properties and non damaging effects on the metal composition due to its high reflectivity render it as an important tool for soft tissue lasing [4].

The erbium family of lasers is similar to the CO_2 wavelength in some respects. There is minimal depth of penetration in soft tissue and reflection away from the implant surface. Chryssikopoulos *et al.* [15] demonstrated precise cuts in the oral mucosa by dry ablation using erbium: yttrium-aluminium-garnet (Er:YAG) laser with small diameter tips and pulse repetitions of 8 to 10 Hz, thus warranting its use during soft tissue procedures. But, the erbium family of lasers lack significant hemostatic capability unlike CO_2 or Nd:YAG [4].

Moreover, there is evidence to suggest that the diode wavelength group, delivered in low power CW values (1-2 Watts average power), causes minimal damage to the implant [11] or surrounding bone [16, 17]. Hence it could be regarded as the instrument of choice for osseous procedures. Such an application is in addition to its primary indication for soft tissue procedures. (Figure 2)

Fig 2: Figure shows Biolase™ diode soft tissue laser

4.1.2 Laser as an aid in sub-periosteal implant placement

The subperiosteal implant is a custom-fabricated titanium framework designed to rest on top of the mandibular bone, under the periosteum, and which is stabilized by a combination of fibrous tissue and bone support [18]. The support and attachment for prosthesis in such a scenario is mainly dependent on permucosal extensions. Although not favoured in contemporary practice in comparison to endosseous fixtures, it is still an option in few clinical situations [19]. A study done by Hjorting-Hansen *et al* [20]. indicated highly predictable osseointegration and reduced technique sensitivity with subperiosteal titanium frameworks made via stereolithography, compared to endosseous implants. Concurrently, Kusek [19] used Er;Cr: YSGG laser in the successful placement of sub-periosteal implant manufactured by the aforementioned procedure. Flap reflection was accomplished using the setting of 1.25 W 30 Hz 7/14 in the hard tissue mode followed by mandibular decortication at 3.5 W 30 Hz 30/60 in hard tissue mode to initiate primary access for the bone screw. Furthermore, YSGG laser was used at a low level (0.75 W 0/14 20 Hz) to tissue weld and stimulate angiogenesis. A preference over conventional surgical drill was presented due to various reasons as follows:

1. Elasticity of tissues could be maintained thus aiding in primary closure.
2. Faster blood supply to the flap could be permitted using the laser in a defocused mode with low-level radiation on the surgical site thereby ensuring quicker healing than traditional methods.
3. Multiple decortications into the alveolar bone were carried out starting regional acceleratory phenomenon.
4. Minimal post-operative pain or swelling.

4.1.3 Laser bone irradiation as a means of bio-stimulation

As stated before, Er:YAG laser (2940 nm) ablates bone effectively and efficiently with minimal thermal damage as a result of complex interaction of laser energy with water and tissues (hydrophotonics) [21, 22]. Also review of recent literature [23] reveals that Er:YAG laser irradiation has a low-intensity laser-like effect by activating surrounding cells, and has a biostimulatory effect on the process of wound healing, fibroblast proliferation, collagen synthesis [24], and bone regeneration [25]. Pourzarandian *et al.* [24] reported that Er:YAG laser irradiation stimulated the proliferation of cultured human fibroblasts through the production of platelet derived growth factor (PDGF). Kesler *et al.* [25] demonstrated in a pilot rabbit study that implant site preparation with the

Er:YAG laser results in good healing and a significantly higher percentage of bone to implant contact as compared with conventional osteotomies. Lubart *et al*. [26] reported that the Er:YAG laser enhances wound healing by releasing reactive oxygen species. Kesler *et al.* [23] clarified effects of the Er:YAG laser on the bone healing through a detailed histologic and histochemical assessment and concluded that Er:YAG laser irradiation seemed to stimulate the secretion of PDGF in osteotomy sites in a rat model. Thus the above-mentioned was proposed as a possible mechanism for improved healing of osteotomy sites after Er:YAG irradiation.
However irrespective of the intent of surgical laser usage, tissue cutting is always a thermally induced explosive process [27, 28]. It is essential to maintain coaxial water spray to prevent heat damage, which would delay healing. Bone composition is very similar to dentin from the perspective of laser/tissue interactions. Thus, in maxillary alveolar bone, the speed of laser cutting should be equivocal to a bur, but in the mandible it ought to be a tad slower, owing to greater mineral density of cortical bone. Equally important is to avoid excessive power parameters to reduce the ‘‘stall-out’’ effect of debris and to minimize blood-spatter. Laser power values of 350–500 mJ/10–20 pps (average power range 3.5–7.0 watts) with maximal water spray appear to produce good ablation rates [23].

4.1.4 Laser in the clinical management of severe peri-implantitis (PI)

Another interesting use of lasers in implant dentistry is the possibility of salvaging ailing implants by decontaminating their surfaces with laser energy [4]. Until now, different therapeutic strategies have been described for the clinical management of PI but, with variable efficacy. Such treatment aims for elimination of plaque and calculus, decontamination of the failing implant surface, and regeneration of lost bone tissue. Surface decontamination can be accomplished with the use of chemical agents (eg, chlorhexidine) or mechanical (eg, ultrasonic) or photonic (eg, laser) devices [29].
Diode lasers were used in a study by Bach *et al.* [30] who found a significant improvement in the 5-year survival rate when integrating laser decontamination into the approved treatment protocol. Dortbudak *et al.* [31] found that the use of low-level laser therapy with a diode soft laser 905-nm for 60 seconds after the placement of toluidine blue O for 1 minute on the contaminated surface attained complete bacterial elimination. Shibli *et al.* [32] found a positive correlation in the use of a diode laser and toluidine blue O suggestive of lethal photosensitization of cell membranes.
CO_2 lasers have also been successful in decontaminating implant surfaces. Kato *et al.* [33] demonstrated the same with expanded beam of CO_2 laser while Mouhyi *et al.* [34] found combination of citric acid, hydrogen peroxide, and CO_2 laser irradiation to be effective for cleaning and re-establishing the oxide structure of contaminated titanium surfaces. Deppe *et al*. [35] and Romanos [36] through their investigations also arrived at a similar conclusion.
Many preclinical and clinical studies have reported high efficacy of Er:YAG laser (ERL) for debridement/decontamination of implant surface. Furthermore, Badran *et al.* [29] successfully managed a case of severe peri-implantitis by following a 2-stage debridement protocol using erbium-doped yttrium aluminium garnet (Er:YAG) laser device in non surgical and surgical mode as well. Schwarz *et al.* [37] found potent bactericidal properties of such lasers with no morphologic implant surface alterations detected.
On the contrary, Block *et al*. [9] conducted a study on Nd:YAG lasers and found minimal sterilization potential on commercially available endosseous fixtures along with a host of deleterious effects on implant surfaces. Kreisler *et al.* [38] compared various laser families and were of the opinion that Nd:YAG and Ho:YAG lasers were not suitable for decontamination of dental implant surfaces at any power output. At the same time, Er:YAG and CO_2 lasers need to be used at limited power output so as to avoid surface damage.
However, Miller [39] believed that all previous lasers tested for potential use in oral implantology work in vapourization mode which could lead to undesirable surface alterations and deleterious tissue changes. Erbium Chromium: Yttrium Scandium Gallium Garnet laser (Er Cr: YSGG) operating at 2780 nm which ablates tissue with a hydrokinetic effect was put forth as an alternative instead. In an in-vitro comparison with citric acid debridement, Miller [39] found superior ablation of the HA coated surface with absence of smear layer.

4.1.5 Immediate implant placement – Laser a boon

Traditional methods for dealing with infected potential implant sites have involved treatments performed in stages much to the disapproval of patients and clinicians alike. Immediate implant placement, on the other hand, can be practiced but with adherence to certain norms which includes pre-surgical alveolar debridement. Whereas conventional chemical debridement can be achieved at 100 mm level, hydroacoustic effects of laser technology has shown to accomplish the same at a level greater than 1000 µm [40]. Reports by Crispi *et al.* [41] have also shown debridement of the root surface and primary osteotomy site free from any damage. Kusek [40] through a series of 10 case reports, provided evidence for aforementioned bactericidal effects of hydroacoustic laser technology of Er, Cr:YSGG laser, thus warranting its use in predictable immediate implant placement.

4.2 Non-surgical use of lasers

4.2.1 Laser-welded titanium framework technology

Laser-welded technology has become a viable alternative to the conventional lost wax-casting technique in the field of implant dentistry. The properties of titanium offer many advantages for its use in bar superstructures, which when coupled with precision offered by laser energy allows for a much stronger, passively fitting superstructure [42, 43]. Literature is replete with scientific evidence establishing precision fit of titanium superstructures. Bergendal and Palmquist [44, 45] reported that titanium frameworks compared favorably with cast-alloy frameworks with no statistical significance in implant loss, framework fractures, component fit, or margin bone loss. A 5-year study by Ortorp *et al.* [46] showed that success of laser-welded titanium frameworks parallels cast-alloy frameworks. Recently Jackson [47] reported favourable application of laser-welded titanium frameworks in treatment of three totally edentulous patients. However, he pointed out prosthetic veneer fracture from the superstructure as a possible complication, thus stressing on the need for a disciplined, predictable approach to the fabrication of such superstructures.

4.2.2 Laser-oriented Recording on Dental Prostheses

In this modern era of biological warfare and active terrorism, forensic dentistry assumes fundamental importance in medico-legal investigations. Apart from conventional methods, identification by DNA analysis and IC tags has also proven to be valuable [48]. To meet the perennial demand for increase of information storage capacity, femtosecond pulse laser systems have been developed, which offer microfabrication on various materials with high spatial resolution [49, 50]. Utilizing a sapphire diode laser, Ichikawa *et al*. [48] demonstrated precise and super-fine etching of 10-μm-square characters on the surface of commercially pure titanium without any thermal damage. Nonetheless, durability testing of such surfaces against chemical and physical stresses would need to be conducted before the aforementioned concept can be completely accepted by the dental fraternity.

5. Conclusion

The challenge for the dental practitioner is the same as for any other area of medicine: knowing when, where, and what armamentarium to use in any given situation. Considerable research into the many permutations of laser wavelengths and target sites has allowed a refinement of criteria and a balanced approach to laser use. Dentistry has entered an exciting era of technology, with lasers offering the dentist not only a window, but a door into this rewarding and potentially profitable arena.

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