Laser dentistry: Membrane-based photoacoustic and biostimulatory applications in clinical practice

BY PROFESSOR LAURENCE J. WALSH

Published data clearly support the value of lasers in many fields of dentistry. The challenge for the practitioner is knowing when, where, and what armamentarium to use in any given situation, since not all laser wavelengths are necessarily useful in every clinical situation. The current range of applications for lasers in dentistry is so broad that to cover the field in any depth requires a large textbook. (The book "Oral Laser Applications", co-authored by LJ Walsh, was published by Quintessence in July 2006, and is a useful source of contemporary information on laser dentistry).

Two examples of applications of lasers attracting current interest which I will discuss in this article are photomechanical effects for creating analgesia for hard and soft tissue procedures; and biostimulation for promoting rapid integration of implants. Despite their obvious differences, in terms of mechanisms, both rely on the effect of lasers on membranes - the cell membrane and the inner mitochondrial membrane, respectively.

Figure 1. Before and after photographs of the treatment of deep caries with an Er:YAG laser in a young patient with the "worst case" scenario of an unrestored canine tooth with rapidly progressive caries on the buccal surface. A gingivoplasty has also been undertaken to gain access to all the margins - note the lack of bleeding. The margins show laser etching.

Laser-induced analgesia

Early work with free-running pulsed Nd:YAG lasers in the early 1990's showed that pulsed laser radiation which could penetrate dentine was responsible for part of the desensitizing effect on cervical dentine, the remainder of this effect being a partial occlusion of dentinal tubules. Subsequent studies of laser-induced analgesia with the free-running pulsed Nd:YAG and Er:YAG laser by Orchardson and Zeredo, respectively using rodents showed conclusively that there was a dramatic blockage of neuronal activity and a corresponding increase in the pain threshold of teeth after laser irradiation. The effect had a clear dose response for its onset, declined after 15-20 minutes, and was also associated with blockade of late-phase neurogenic inflammation (which is driven by the effects of neuropeptides). These effects were identical to those noted in clinical practice when preparing cavities with erbium lasers (Er:YAG and Er,Cr:YSGG). The animal studies however removed all possibility of placebo effects and psychogenic influences, and demonstrated that there was a fundamental reversible alteration occurring in the nociceptive response caused by the laser treatment, which suppressed nerve firing for a given level of stimulus.

Clinically, the blockade with shorter exposures is more selective for depolarization of A delta fibers (rapid, sharp, well localized pain) than for C fibers, which explains why some patients notice low level photomechanical shock waves ("mini-earthquakes") but not discomfort. Laser analgesia is known to be induced at sub-ablative settings, which give high penetration of both teeth and soft tissues (e.g. through to the pulp via the attached gingival and alveolar bone). Because of some persisting C fiber activity, some patients notice cooling effects in their teeth during lasing due to evaporative energy loss (the thermodynamics dictate that with a net energy loss, pulpal cooling of up to 7 degrees Celsius may occur). These mild sensations would be more likely to occur in younger patients, and in previously unrestored teeth with rapidly progressive caries on the buccal surfaces of canine and premolar teeth, as these have the shortest, straightest, and widest dentine tubules in adult patients, and the least secondary dentine (Figure 1). Achieving reliable laser analgesia as a pre-emptive step in such cases involves using the lower energies and higher pulse frequencies which give the penetrating analgesic effect rather than surface ablation of tooth structure.

Since microscopic studies on both animals and humans had shown the laser analgesia effect was molecular, not histological, the intellectual issue then arose of the targets involved. An obvious explanation could be that low level stimulation of A delta fibers by laser pulses could initiate gate control, in a pattern similar to transcutaneous or trans-mucosal electrical stimulation. However, when investigating this effect, changing the frequency of

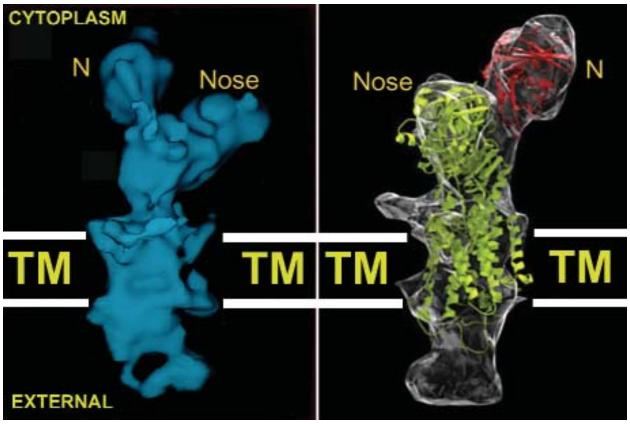

Figure 2. Two molecular models of the NaK pump, showing external, transmembrane (TM) and inner cytoplasmic parts, based on the work of Bill Rice and David Stokes at NYU. The red domain on the right image is the beta domain. For an animation of the pump working, see www.mark-hilge.com/nak/nak-atpase_f.htm

Figure 3. Gingivoplasty in an orthodontic patient undertaken without LA using the Er:YAG laser. Note how the soft tissue contours match those immediately after surgery. The patient did not undertake any mechanical or chemical oral hygiene during the 2 weeks after the surgery.

pulsing the laser suggested that a resonance effect was occurring, since there were core frequencies which were effective, as well as harmonics of these (10 Hz, 20 Hz, etc). The putative target for a photo-acoustic effect identified by the author was the Na/K ATPas pump. The work of Rice at NYU has shown that this is a hollow tubular protein which spans the cell membrane of nerves, and establishes the gradients in sodium and potassium which are essential for propagating an impulse down a nerve through membrane depolarization and repolarization. The term "bioresonance" has been coined by the author to explain how partial spatial dissociation of the beta domain of this ion channel protein (which controls its function) closes the lumen of the "pipe" and thus prevents repolarization for a short period of time (Figure 2).

Using water mist to couple laser energy into soft tissues, analgesia can be exploited for soft tissue procedures as well as for cavity preparation. Animal studies by Zeredo's group have confirmed that Er:YAG laser incisions to lip, gingiva, mucosa, and tongue are less painful than with scalpel, when both are undertaken without local anaesthesia, scientifically validating the clinical experience of many laser dentists who undertake minor procedures such as gingivoplasty during cavity preparation without causing discomfort (Figure 3).

Biostimulation

The second laser application under the spotlight is low level laser therapy (LLLT), also known as soft laser or biostimulation. This effect is a photochemical effect caused by the action of visible red (633-635 nm) or near infrared (810-830 nm) light on the electron transport chain in mitochondria, which activates NADPH oxidase (and other enzymes) in the inner mitochondrial membrane, and causes a broad activation of normal cellular functions. Exploiting this to accelerate bone behaviour in terms of integration and regeneration around implants is attracting current interest. Many clinical studies (including randomized controlled clinical trials) have shown that LLLT is of proven benefit in wound healing for soft tissues, accelerating closure of oral mucosal soft tissue wounds by facilitating the healing process at the level of both the microvasculature and fibroblasts. Maximum benefit with LLLT occurs with repeated dosages, with the best effects being obtained when the treatment is applied daily or every second day.

Recent work has shown that LLLT may accelerate metabolism and/or mineralization during early bone healing. For example, in a rabbit tibia model, Khadra has shown that LLLT stimulates the mechanical strength of the interface between the implant and bone after a healing period of 8 weeks. Histomorphometric and mineral analyses showed that the irradiated implants had greater bone-to-implant contact than the controls. Using the same model, Lopes noted that LLLT improved bone healing such that the loading time could be reduced to 30 days after LLLT, while Guzzardella demonstrated greater implant-bone contact area and greater bone microhardness. Animal studies using primates have examined the effects of low-energy laser irradiation on osteocytes and on bone resorption at bone sites used for implant placement. When sites are irradiated immediately after drilling before inserting implants, osteocyte viability measured after 5 days was higher compared to non-irradiated control sites, implying that LLLT may have positive effects on the integration. In contrast, the rate of bone resorption was not affected by laser irradiation.

Further studies are underway to determine the benefits of LLLT with various implant placement techniques in humans. Given the expansion of implant dentistry and laser dentistry in recent years, it is logical to anticipate the concurrent use of both technologies in clinical practice as the evidence base consolidates.

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Further reading

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