Pain Investigations for Dental Procedures Using Conventional and Laser Modalities

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It is almost 30 years ago when the first reports on the biological effects of non-thermal laser were published and now we are confident to say that the field of laser therapy is becoming the main topic for many research and clinical articles.1-7 The mechanisms of actions are still a subject for discussion in the research literature but, now with the number of controlled clinical studies reporting positive results on safety and efficacy the evidence is there that light can affect tissue in many ways and that is clinically quantifiable.5-7

Laser wavelengths are specific to the region of spectral emission and their effect on tissue depends on such parameters known as the frequency of the emitted light. In the visible region of the spectrum, the frequency of light is easy to recognize because it is the same as the emitted color. In the infrared region, the emission is not visible and the wavelength is increasing as we approach lasers with frequencies in the middle and far infrared. Lasers can affect tissues in many ways and for therapeutic applications the desired conditions are non-ablative with deep penetration into tissue and a wavelength that stimulates cellular processes. In this report the primary goal is to evaluate pain control and relief in two different applications related to infrared lasers.

The first application is for an Er,Cr:YSGG laser having a wavelength of 2789 nm with strong absorption in water and the –OH bond. This laser has been used mostly in dentistry for removing, incising and excising hard and soft tissues. For the purpose of this study, the discussion will focus on Er,Cr:YSGG laser cavity preparations and the mechanisms responsible for pain control.
Preliminary Assessment of Intra-tubular Fluid Flow During Cavity Preparations using an Er,Cr:YSGG Laser System and High-Speed Drill

In a study by Brännström et al, it was suggested that the dynamics of fluid movement inside dentinal tubules may result in a mechanical stimulation to the nerve endings inside the pulp. In that study, Brännström explained that the outward flow is what produces fluid movement actions responsible for pain. Later, Matthews et al reconfirmed that human teeth are more sensitive to an outward flow of fluids from the dentinal tubules as opposed to an inward flow, or a flow entering the tubules. Currently, there are two types of instruments utilized to prepare cavities in teeth and those are the mechanical high-speed drill and the hard tissue lasers such as the Er,Cr:YSGG and Er:YAG. In this study, our focus is to compare the Er,Cr:YSGG laser to the high-speed drill for their effects in displacing fluids in dentinal tubules.

The high-speed drill is a rotary instrument that uses a bur at 300,000 – 400,000 RPM to remove tooth structure through direct contact which causes vibration, pressure and heat into tissue. All such effects may contribute to fluid movement which contributes pain. The purpose of this experiment is to understand this effect without correlation to the specific causes.

The Er,Cr:YSGG laser with the addition of the water spray removes tooth structures through a sequential vaporization process that generates little vibration, pressure, or heat. The sequential vaporization process relates to the layer by layer rapid vaporization of water present within the structure and the resulting forces that lead to the removal of tissue one layer at a time. The pressure generated in this process is localized. There is very limited laser energy transferred to tissue because the laser pulse is short and almost all energy is used to disrupt tissue mechanically instead of thermally. Also, during disruption, the energy is carried away from the tooth together with the ejected tissue debris and that explains the lack of thermal effect to the dental pulp.

Clinical studies on patients using the Er,Cr:YSGG laser demonstrated that this laser is comfortable to a level that no anesthesia is required in most cavity preparation classes. Such findings have been reported in the literature as well as recent unpublished data.

In this study, the Er,Cr:YSGG laser and a Midwest high speed drill were used to compare and evaluate intra-tubular fluid movement effects. To measure such effects, a laboratory model using a capillary device was developed. The model comprised of a disc of dentin mounted in an acrylic block that has two glass capillary tubes connected at the same level with one side open to the atmospheric pressure and the other side blocked by a syringe filled with distilled water. Figure 1 is the representation of this model with a 2 mm human dentin disc mounted on the acrylic block having a cut as reservoir for water and two 600 µm diameter capillary tubes connected to the reservoir. The circumference of the dentin disc was sealed with epoxy to provide air tight conditions while leaving the rest of the dentin disc permeable to fluid flow. Distilled water free of air bubbles was supplied from the syringe to the
reservoir and part of the open capillary that serve as a fluid flow gauge. The water line to the syringe was clamped shut to close the system. And the entire acrylic block was secured to a metal breadboard to insure no movement from the vibration of the cutting.

The first instrument tested was the high-speed drill using a 1 mm diameter round bur. The drill was operated by hand to create ten individual 1 mm diameter hemispheric cuts that resulted in the fluid displacement measurement (a cumulative effect from all crater preparations).

The second test was for the Er,Cr:YSGG laser (Biolase Technology, Irvine CA) set to emit a 200 mJ of energy per pulse at a repetition rate of 10 Hz. This setting is one of the manufacturer-recommended settings for dentin ablation. Crater cuts in dentin were prepared using a 500 µm diameter quartz tip in a non-contact at approximately 1.0 mm from tissue surface. The laser fluid movement was also a cumulative measure from multiple laser crater preparations into the dentin disc to match the volume removed by the high-speed drill.

For the high-speed drill, the fluid displacement in the capillary was approximately 2.8 mm³ while approximately 2.6 mm³ volume of dentin material was ejected during cutting. In millimeters, the water column moved inside the open capillary approximately 10.0 mm outwards and remained at that location after the high-speed drill was stopped. The displacement of dentin material matched the displacement of fluid from the capillary, suggesting that the displaced mass was translated into fluid movement. On the other hand, the Er,Cr:YSGG laser had no detectable displacement of fluid in the capillary, and visual observations did not detect any visible water column movement during laser ablation. This may be because the Er,Cr:YSGG laser removes tissue through a sequential vaporization process that vaporizes in thin layers.
and with localized pressure build-up and release. This would cause any expansion and contraction of water to take place in very small amounts at very high speeds thus maintaining fluid levels in the inter-tubular structure without substantial detectable flow movement in this experiment.

A possible explanation for why the drill displaces fluid, while the Er,Cr:YSGG does not, lies in the mechanism of tissue removal. A drill removes tooth structure through a bur that is rotating at 300,000-400,000 RPM which continually impinges upon the tissue to create strong forces to displace fluids in capillary. The Er,Cr:YSGG laser’s sequential vaporization mechanism combined with the small volume of tissue removed at each pulse would allow the fluids to expand and retract on the millisecond timescale. The Er,Cr:YSGG laser ablation process allows the tissue and fluids to stabilize in-between each pulse, returning to equilibrium. Based on this experiment it is clear that the Er,Cr:YSGG produce no displacement of water as compared to the continually impinging high-speed drill. As Matthews, building on Brännström’s theory, suggests that fluid movement is a primary cause of pain in hard tissue dental procedures, the results of this study provide a possible explanation as to why the laser induces less pain than the high-speed drill. 8-10

An Assessment of Therapeutic Treatment of Temporomandibular Joint (TMJ) Disorder using a GaAlAs 815nm Diode Laser System

If all laser wavelengths had strong absorption for significant tissue chromophores such as the absorption of the 2789 nm laser in water, tissues would qualify as just absorbing media and that is non-scattering. In that case the distribution of laser energy in tissue would be easily described by a simple Beer’s laws of exponential attenuation.

\[ E(z) = E_0(1-r_{sc}) e^{-(\mu_a+\mu_s)z}; \]

\( E(z) \) fluence of light at position \( z \) in tissue \([\text{w/cm}^2]\), \( E_0 \) irradiance, \( r_{sc} \) surface specular reflection, \( \mu_a \) absorption coefficient \([\text{cm}^{-1}]\) and \( \mu_s \) scattering coefficient \([\text{cm}^{-1}]\);

But that does not apply because, laser wavelengths are not always highly absorbed and a good example is the near infrared region where properties are such that require special conditions in the components of the tissue target. Because tissue is light in color and the near IR wavelengths show a great affinity for very dark chromophores, scattering becomes high for lasers in this category. Scattering is usually caused by random spatial variations in tissue density, refractive index and dielectric constant and actual laser light distribution can be substantially different from distributions estimated using Beer’s law. For therapeutic application this effect plays an important role because it will allow for the transfer of minimally attenuated but diffused laser energy to deeper structures into the tissue.

In one experiment, an IR camera and a near-IR laser source were placed on opposite sides of, and in contact with, a tissue sample of a known thick-
ness. The near-IR laser source was activated, and an extinction depth of approximately 20 mm into the tissue sample was measured with the IR camera. The laser was an 815±15 nm AlGaAs solid state diode with an output power of 0.6 W of continuous wave and a spot size of 7 mm. With the understanding that deep tissue penetration is possible when using the near IR lasers we are going to review some of the the reported mechanisms of action attributed to effects that occur at the cellular and tissue structure levels.

**Photo-activation of inactive enzymes present in painful muscle tissue**

Muscle cell dysfunction is induced by reactive oxygen atoms, or molecules containing oxygen that can either produce free radicals or are chemically activated by them. ROS are cleared from cells (e.g. muscle cells) by the action of catalase, glutathione (GSH) peroxidase or superoxide dismutase (SOD). According to experimental work by Bolognani and Volpi, low levels of laser energy can reactivate enzymes and affect enzymatic activities in tissue. 2

**Increased production of cellular ATP in dysfunctional muscle tissue**

The interaction of myosin and actin in muscle requires ATP and its absence may contribute to painful dysfunction. According to Karu3, a possible cellular response to laser is an increase in ATP production. An increase in ATP may contribute to improved cell function and relief of pain.

**Direct action on the nerve fibers**

In an animal study by Kudoh4 et al, it was suggested that changes of Na-K-AtPase activity in LLLT treated peripheral neural tissue are associated with the pain attenuation process.

**Blood Flow Enhancement**

Blood flow increase has been reported to help with tissue repair and healing. 5-6

**Presentation of Case Study on TMJ treatment using AlGaAs laser diode at 815 nm wavelength**

This case involved a 42 year-old female. Patient indicated that she had first started to suffer from chronic TMJ pain about 16 years ago and pain has resolved and restarted at various times. This particular condition of TMJ pain started one week before the first appointment. The patient was only capable of opening her mouth 15 mm vertically on her own; the jaw could move laterally 2mm to the right, 4mm to the left, and 2mm forward/backwards. An algometer device was used to determine pre-operative levels of discomfort at various trigger points and the patient...
was asked to mark a VAS scale. The pressure applied was approximately 2.1 lb which resulted in a marking of the VAS at 81 mm. Patient was diagnosed with TMJ arthralgia on the left side of the jaw, and a series of treatments over three weeks using the 815 nm diode laser were initiated immediately. Each painful trigger point detected from application of constant pressure at different locations of the masseter or the temporalis was treated for 60 seconds at a fluence of 1.47 J/cm² for a total of 33.5 joules per trigger point. The TMJ was also treated using the same dose at three locations: 1) the posterior aspect of the main nerve supply to the joint; 2) anterior aspect of the joint at the point of insertion of the lateral pterygoid muscle into the condyle and 3) interior of the joint, the intra-articular compartment.

Treatment results for this patient at six treatment points (T-1, T-2, T-3, T-
4, T-5 and T-6) and two follow-ups (F-1 and F-2) are reported in the Figure 2 and 3. The measured results reported in Figure 2 are as follows: TVO – Vertical opening [mm]; LATR – Lateral right [mm]; LATL – lateral left [mm]; PROT – forward [mm]. Figure 3 measurements are for the VAS [mm].

At the conclusion of treatment, the patient was capable of opening her mouth 32 mm vertically on her own; the jaw could move laterally 7mm to the right, 9mm to the left, and 4mm in the forward direction. The final VAS scale measurement was 22 mm; generally speaking, a 2-4x reduction (improvement) in the assessment metrics.

In another case the patient (male, age 26) indicated a score of 80 and 90 mm on the VAS scale and the pain was so severe that it interfered with normal daily activities for over one year. Treatment was carried out the same way as for the first reported case.

Treatment results for this second case at five treatment points (T-2, T-3, T-4, T-5 and T-6) are reported in Figure 4 and 5. The measured results reported in Figure 4 are as follows: TVO – Vertical opening [mm]; LATR – Lateral right [mm]; LATL – lateral left [mm]; PROT – forward [mm]. Figure 5 measurements are for the VAS [mm].

At the conclusion of the entire treatment, the patient was capable of opening 56mm vertically on his own (+15mm); the jaw could move laterally to the right 13mm (+3mm), to the left 10mm (+1mm), and forward 11mm (+1mm). The final VAS scale measurement was 6 mm (-14mm from Treatment #6 pre-op; -94 mm compared to Treatment #2).

Interestingly, the scores reported in the first case did not show any consistent progression during treatment. Lateral and forward jaw movement showed slight improvement over the course of treatment and VAS pain actually increased during the first few treatments. It was not until treatment five that this patient showed a significant drop in VAS pain and increase in vertical mobility that carried through the follow-up appointments. The first patient had
the same progression as the second case where initial there was very slow progress and most of the change occurred after treatment 5.

That slow progression with a significant improvement by treatment 5 (2 - 3 weeks later) support theory of a slow repair process that will require time to reverse the tissue damage responsible for the initial painful condition.

Recently, cases with painful TMJ conditions have been treated with a new wavelength, 940 nm, and short-term results have been very positive. More work will have to be done to conclude on the effectiveness of either 810 or 940 nm wavelength primarily for long term effects.

Conclusion

The laboratory and clinical case studies presented in this report require further analysis through wider clinical assessment. The results from both studies dovetail with existing literature, and support the suggested mechanisms of action that cause, and reduce, pain encountered through dental procedures. Additionally the same studies provide insights into further research required to develop means to relief pain in muscle and joints and reduce patient discomfort during procedures on teeth.

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