Endodontic Applications of a Short Pulsed FR Nd: YAG Dental Laser: Treatment of Dystrophic Calcification A Clinical Trial Report

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ABSTRACT

Formation of dystrophic calcification deposits within the root canal of a tooth, have historically been difficult clinical endodontic complications. Presently, removal of such tissue, mineralized through the deposition of calcareous materials in a root canal (a "calcified canal"), remains resistant to conventional endodontic techniques. The subsequent treatment primarily involves undesirable surgical procedures and/or loss of the tooth. Described in this clinical trial is a technique using free running (FR) pulsed, Nd: YAG laser energy to ablate hard calcified tissue which obstructed mechanical access of the root canal and root apex -- a technique employed after conventional endodontic methods failed. This paper discusses the "plasma" effect, "spallation", canal illumination and transillumination using the helium-neon (HeNe) aiming beam. A free running pulsed, FR Nd: YAG dental laser was successfully used at 20 pulses per second and 1.75 watts to photovaporize and photodisrupt enough calcified tissue obstruction, to allow a conventional endodontic file to pass the canal blockage, and access the root apex. This clinical trial achieved the immediate, short term objective of endodontic hard tissue removal via photovaporization and photodisruption. The pulsed FR Nd: YAG dental laser used as described in this clinical report appears to be a very safe and very effective technique; offers a treatment alternative to traditional therapy that suggests high patient acceptance; and is significantly less stressful for the doctor and staff than traditional treatment options. Long-term, controlled scientific and clinical studies are necessary to establish the safety and efficacy of both the helium-neon energy for visualization and the low-watt pulsed FR Nd: YAG energy for photovaporization and photodisruption of hard calcified tissue within the root canal. Research is especially needed to understand the effects of a low-watt, pulsed FR, Nd: YAG laser on the activity of osteoclasts and odontoclasts and identify risks for developing external and/or internal resorption after intracanal application of pulsed FR Nd: YAG laser energy.

KEY WORDS: Nd: YAG Laser, Endodontics, Root Canal, Dystrophic Calcification, Transillumination, Plasma, Photoablation, Photodisruption, Photovaporization, Spallation.

1. INTRODUCTION

Research papers of lasers for use on dental hard tissue were first published in 1964[2,3]. The earliest reported study that focused on the use of lasers in root canals appeared in 1982[4]. Extensive laser endodontic research began in 1984[5,6] and has been intensive ever since. Most laser endodontic studies by dental researchers have centered on the carbon dioxide (CO_2)[7-9] and the neodymium: yttrium-aluminum-garnet (Nd: YAG)[10-18], with investigational research involving the ultraviolet (UV) eximer laser just recently in 1989[19,20]. Research specific to pulsed FR Nd:YAG laser usage in dentistry investigated other hard tissue procedures without damage to tooth pulp, surrounding tooth enamel and dentin, and minimal associated discomfort[21-41].

The last three years has seen a tremendous number of scientific investigations, clinical trials, and clinical procedures using a pulsed FR Nd: YAG dental laser with variable repetition rates of 10,15, 20, 25, and 30 pulses per second (pps) or hertz (Hz) which are controlled by the operator. This variable pulsed FR, Nd: YAG dental laser has been, and is being used by over 600 clinical practitioners in the United States, and 900 worldwide, for numerous hard tissue procedures involving the hard tooth structure. No pulsed FR Nd: YAG dental laser commercially available has yet received hard tooth and bone tissue marketing clearance from the U.S. Food and Drug Administration (FDA). However, most countries outside of the U.S. have authorized the clinical use of FR Nd: YAG laser energy for hard tissue laser procedures.

The contact fiber laser handpiece is used in the same manner as an endodontic explorer and can be used within the tooth where access is difficult with the dental air rotor handpiece. The interaction of laser wavelength and energy density with tissue at the tip of the fiberoptic contact delivery system allows simultaneous vaporization and acoustical disruption of calcified hard tissue. This clinical case report involves the use of the FR Nd: YAG laser to assist in the access of a root canal which was obstructed by deposition of calcareous materials.

2. CLINICAL PROBLEM

Complete removal of pulpal tissue from the apical area, and a complete root canal preparation, are often not possible using conventional endodontic methods[42-45]. *In vitro* research of laser use on inorganic and calcified tissue has been previously reported[46]. However, no studies have been published reporting successful clinical outcomes of *in vivo* Nd: YAG laser energy to ablate or disrupt calcified tissue deposits within a root canal. The primary goal of this clinical trial was to determine if the laser could be used to perform intraoral hard tissue surgery of calcified tissue while reducing or even eliminating the need for extensive endodontic or oral surgery.

2.1 Presentation and Diagnosis

A 27 year old male presented for a dental emergency on August 27, 1990 with a chief complaint of acute, spontaneous and throbbing pain in the upper right maxillary quadrant. A periapical (PA) radiograph of the area, taken during the patient's first office visit on May 9, 1989, shows no apparent pathology [Fig. #1]. The patient's maxillary right first molar--tooth #3--was very painful to percussion. A diagnostic PA radiograph was taken on August 27, 1990 of tooth #3 [Fig. #2]. (Note: On June 27, 1989, extensive decay was removed from tooth #3, and a temporary restoration was placed. Approximately 12 months later--on June 11, 1990--a full coverage crown was placed on tooth #3 as a definitive restoration [Fig. #2].) Irreversible pulpitis of tooth #3 was diagnosed.

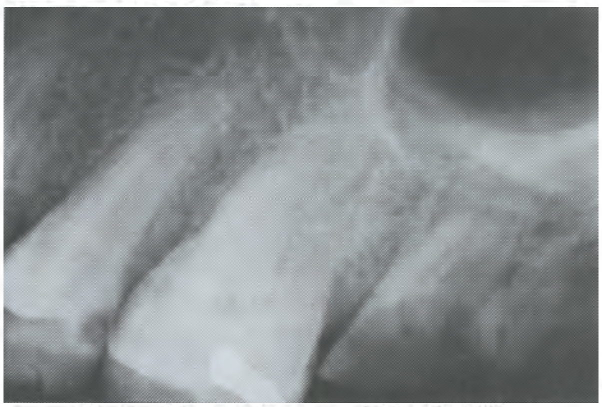

Fig 1. Diagnostic x-ray of May 9, 1989.

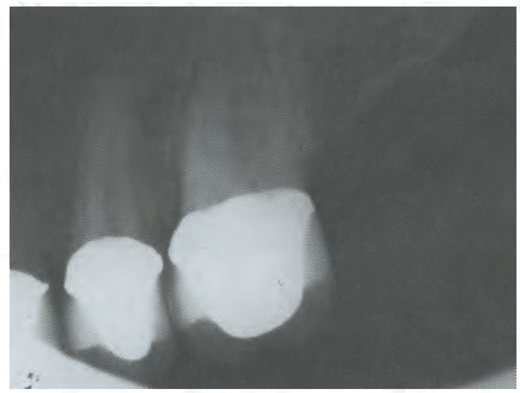

Fig 2. Pre-op x-ray of August 27, 1990.

2.2 Initial Treatment

On August 27, 1990, the PFM crown was removed using an air rotor dental handpiece and carbide bur to assist access and visibility of the roots canals. Conventional root canal therapy was initiated using the dental handpiece and carbide bur to access the root canal openings. Three canals were identified: the mesial-buccal (MB), distal-buccal (DB), and the palatal (P). Apical access of the three canals was attempted with standard endodontic methods. The apices of the mesial-buccal and palatal canals were easily accessed, conventionally treated, and subsequently filed and filled with gutta percha and canal sealer without complications [Fig. #3 & 4].

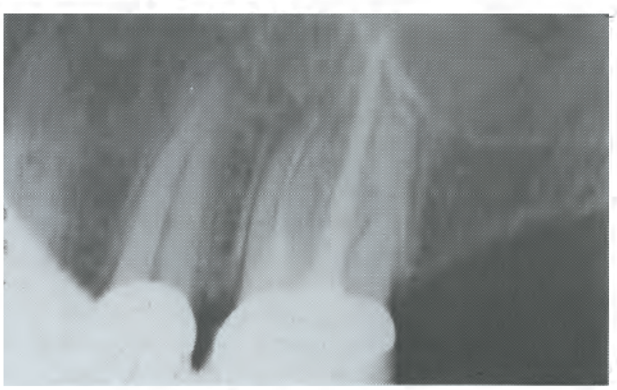

Fig 3. Treatment x-ray of August 27, 1990.

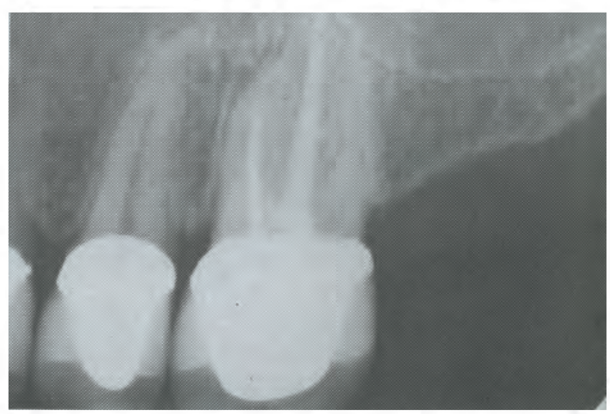

Fig 4. Post-op x-ray of August 27, 1990.

2.3 Complication

Access and mechanical instrumentation of the distal-buccal root canal and apex was not achieved using standard endodontic files. The coronal one-third of the root appeared relatively straight on the x-ray. This root anatomy allowed a white-light fiberoptic cable for direct visualization of canal dentin and calcified tissue in the coronal one-third of the root. Mineralized hard tissue deposits were visible in the canal, and distinguishable from root dentin. The DB canal was obstructed immediately past the DB canal opening. Hand and rotary instruments were successful in the safe removal of calcified deposits in the coronal one-third of the DB root canal.

However, direct visualization was not possible at the mid-root curvature, where the canal remained obstructed. The mid-root curvature also complicated the orientation and safe access of hand instruments and handpiece heads. The limited length of the hand instruments and handpiece burs, further restricted additional depth of access.

A sharp endodontic explorer and "K" files #8 through #20, the careful use of air rotor drill with #4 and #2 round carbide burs; and #1, #2, and #3 Gates-Glidden burs, did not achieve apical access past the mid-root curvature of the DB canal. The DB canal remained inaccessible at the mid-root curvature, Due to the mid-root curvature and depth, visualization was not possible making the orientation of instrument and burs uncertain. As such, there was a very high risk of perforating the disto-buccal root with continued use of hand and rotary instruments. The patient was informed In addition, no periapical radiolucency was evident on the distal-buccal root [Fig. #4]. The decision was made to determine whether the disto-buccal canal was completely calcified by prescribing antibiotics, and allowing time for the infection to subside. On November 5, 1990, the patient returned in pain. A radiograph confirmed a periapical lesion of the disto-buccal root [Fig. #5].

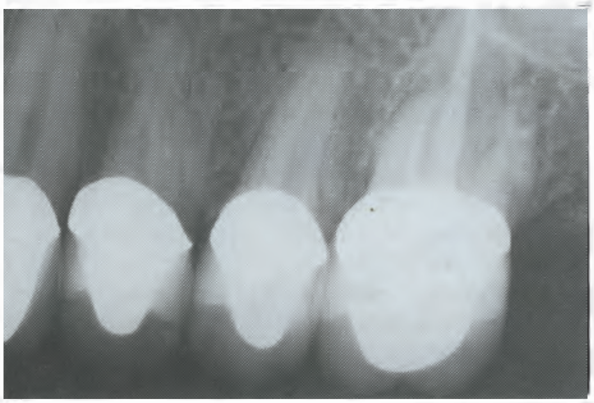

Fig 5. Diagnostic x-ray of November 5, 1990.

2.4 Canal illumination and trans-illumination

The fiber of the FR, Nd: YAG laser was introduced into the disto-buccal canal. The helium-neon (HeNe) aiming beam provided canal illumination which allowed for direct operator visualization of the canal space. Transillumination from the HeNe beam resulted in visual differentiation of canal dentin and calcified tissue.

2.5 Laser ablation of obstruction

On November 5, 1990, the patient requested an attempt be made with the FR, Nd: YAG laser, versus extraction or a surgical procedure to access the root apex through the soft tissue mucosa and bone (apicoectomy and retrofill). Setting the *dLase 300®* on 20 pps and 2.00 watts, the obstruction was cleared in less than one second.

Though very rough and irregular upon first insertion, a #8 file was able to pass the obstruction, and the canal was treated conventionally. [Fig. #6 & #7]. Equally impressive was the ability to use the red helium-neon laser (the HeNe beam) as a light source inside the PFM crown. This allowed a clear and unobstructed view of the obstructed area in the canal space, and allowed the fiber to easily direct the FR, Nd: YAG beam down the long axis of the canal, thus avoiding angling the laser to the lateral canal wall.

2.6 Canal instrumentation and obturation

The photoablation of calcified tissue and canal debris was sufficient to allow a #10 "K" file to pass by the obstructed area, and to access the canal apex. Conventional modalities were subsequently used to enlarge and fill the disto-buccal canal.

Fig 6. File insertion x-ray of November 5, 1990.

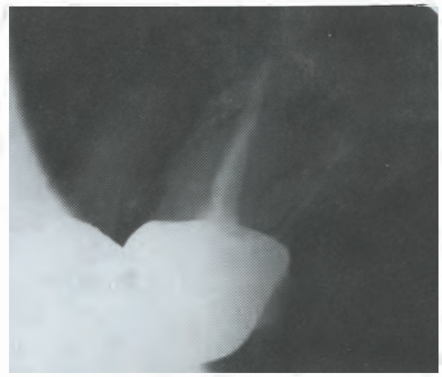

Fig 4. Treatment x-ray of November 5, 1990.

3. MATERIALS AND METHODS

A pulsed FR Nd:YAG laser (*dLase 300®* manufactured for American Dental Laser of Troy, Michigan by Sunrise Technologies, Inc., Fremont, CA) was used to ablate and disrupt intraoral/intracanal hard tissue. The laser energy was directed to the treatment site through a flexible quartz optical fiber with a focal spot diameter of 320 µm. The instrument has a variable average power range of 0.30-3.00 W, and the number of pulses per second is 10-30 hertz (Hz), resulting in an energy range of 30-150 mJ per pulse. Each pulse width is 150 µsec. Because the FR Nd:YAG laser beam is invisible at its operating wavelength of 1.06 µm, a red helium neon laser at 0.63 µm provides a visible aiming beam coaxial with the YAG laser. The tip of the 320 µm optical fiber was extended from the end of an adjustable handpiece approximately 6 mm.

Total energy exposure of the fiber tip and at the target tissue was measured using a hand held pulsed energy meter designed specifically for pulsed FR Nd:YAG dental laser systems (a JD-500 Digital Meter™ and a J25LP Laser Probe™ Joule manufactured by Molectron Detector, Inc. of Portland, Oregon). The pulsed energy meter includes a fiber optic adaptor, laser attenuator, and calibration at 1.06 µm. Actual pulse energy output of the fiber optic is measured in millijoules at any desired repetition rate between one and 600 pps. The pulsed energy meter can measure peak pulse energy output, average pulsed energy, and total energy exposure over time. This allows the operator to determine the exact energy delivered to the target tissue during a particular dental procedure.

All laser procedures were performed with protective eyewear on the patient, dentist, and assistant. Gowns, gloves, and masks were worn by the dental personnel. High-volume evacuation was employed to remove ablated and disrupted tissue. After the laser surgery the handpiece was sprayed with an iodophor disinfectant. The tip of the used fiber was cleaved and discarded in a sharps container. The handpiece, cannula, and fiber were then cleaned and sterilized using an autoclave.

4. RESULTS

There were no adverse reactions or complications from either surgical technique. The surrounding dentition, periodontal soft tissues, and bone were unaffected by the laser. There were no surgical or postsurgical complications or sequelae. The patients response was positive and the postoperative course was uneventful. There was no need for special home treatment instructions. Postoperative analgesia was prescribed, but was not needed.

4.1 Photo Ablation, Photo Vaporization--Photo Thermal Effects

When photons of laser light are absorbed by the target tissue at the focal point of the beam, the atoms and molecules of increase the vibrations of their organized structures, which results in the conversion of photon energy into heat or thermal energy. This photo thermal effect causes the tissue to boil and vaporize. Molecular vibration is then converted to heat, which destroys selected tissue. Increased absorption of laser energy, or additional time on the target tissue, will cause molecules in the tissue to similarly increase their rate of vibrations, conversion to heat, and tissue destruction.

4.2 Spallation of calcified tissue

Spallation is the ablation or removal of calcified tissue by a combination of photothermal processes with photodisruptive or acoustical shock effects that rely on high peak pulse power, and microsecond pulse widths. Spallation results from strong absorption of pulsed infrared laser irradiation by the water or hydroxyapatite component of the hard tissue[47,48].

4.3 Photo Disruption--The Plasma Effect

Tissue can be removed independent of laser beam energy absorption by the target tissue. Tissue removal in this case, is not being vaporized. Instead, the atoms and molecules of the tissue are mechanically separated (ionized) and therefore destroyed. This mechanical separation of tissue atoms and molecules occurs as the result of a unique phenomenon of laser photon energy--called "plasma".

Plasma can be seen as a brilliant orange colored halo that forms between the fiber-optic tip and the surface of the target tissue. At the same time, a "pop" or "crack" sound can easily be heard after each pulse of the laser. This is the plasma effect.

Plasma has been referred to as a "fourth state of matter". The plasma effect occurs from the build-up of very high pressures of ionized air and gas, which is first caused by very rapid temperature elevation at the laser-tip. This small area of very high pressure, then, depressurizes explosively--and causes the popping and cracking sounds (like a sonic boom).

The laser beam is not in direct contact with the target tissue--only the plasma and the resulting area of high pressure. It is the explosive release of air pressure (like opening a shaken can of carbonated beverage) that causes the mechanical destruction of the target tissue.

5. DISCUSSION

The laser contact probe was monitored using the helium neon indicator for a uniform round spot. The power setting of 1.75 watts, and total tissue energy exposure ≤ 1200 millijoules, caused no discernible adverse effects to the soft tissue, adjacent teeth, or bone. The FR Nd:YAG laser procedure was extremely well tolerated by all patients. This clinical trial demonstrates the use of the FR Nd: YAG laser for hard tissue removal in tooth structure.

The infection control procedures used in this study are essential to prevent contamination, cross contamination and to insure sterile instrumentation. The fibers were easily cleaned and autoclave sterilization did not effect the fibers performance in delivering the FR Nd:YAG laser to the tissue. It is assumed that the laser procedure reduced the endodontic pathogens but it is not known to what extent. It can be hypothesized that endodontic laser spallation surgery, used in conjunction with conventional endodontic techniques will be an alternative to more invasive surgery. Continued investigation is needed to determine the role of this laser system in procedures and its efficiency used in conjunction with traditional endodontic methods.

5.1 Case follow-up

On a three (3) day post-operative follow-up phone call, the patient reported being free of pain, and was able to chew on the tooth without symptoms. The patient presented in the office on April 1, 1991 for a five (5) month post-operative radiographic evaluation. The patient reported a complete absence of any pain or discomfort since therapy. A radiograph taken on April 1, 1991 of tooth #3 demonstrates bone regeneration around the disto-buccal apex, consistent with healing of the lesion. The radiograph indicates complete periapical healing of the other two root apices [Fig. #8]. A similar radiograph taken six (6) months post-operatively, on May 6, 1991, indicates further healing [Fig. #9]. The patient presented in the office eleven (11) months post-therapy, on October 23, 1991, reporting a complete absence of any pain or discomfort around tooth #3. A radiograph taken at this eleven (11) months post-therapy, indicates the absence of any periapical lesions. It would appear that all endodontic lesions have completely healed. In addition, the radiograph at eleven months shows no evidence of any external resorption activity [Fig. #10, 11, 12].

5.2 Subsequent clinical trials

Subsequent clinical trials involving fourteen (18) calcified root canals were approached conventionally, then lased in a similar manner. In all fourteen (18) canals (100%), a brief laser application allowed for file access past the obstructions. The canals were prepared and filled conventionally.

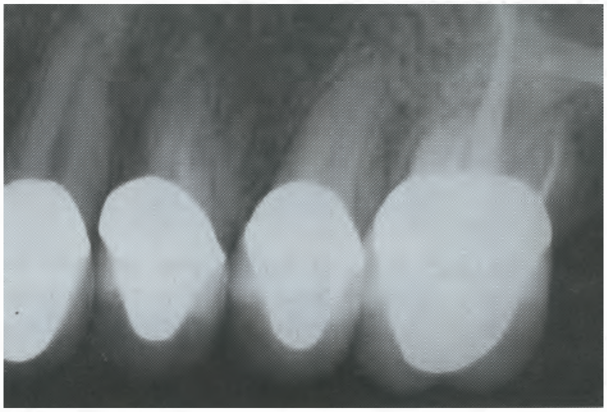

Fig 8. Post-op x-ray of April 1, 1991.

Fig 9. Post-op x-ray of May 6, 1991.

Fig 10. Post-op x-ray of October 23, 1991.

Fig 11. Post-op x-ray of October 23, 1991.

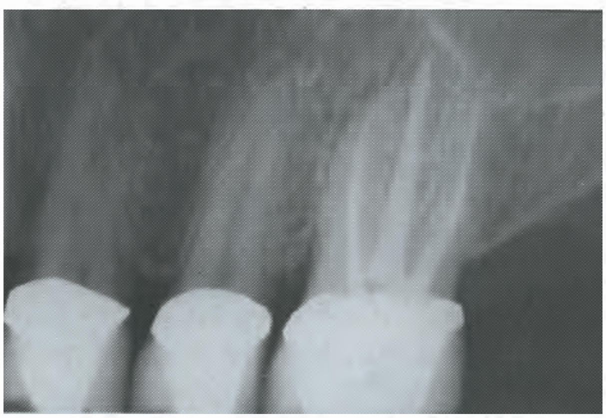

Fig 12. Post-op x-ray of October 23, 1991.

6. SUMMARY

Formation of dystrophic calcification deposits within a root canal will often resist conventional endodontic techniques; and have historically presented unsatisfactory challenges, frustrations, and treatment options for dental practitioners and patients alike. The subsequent treatment options include undesirable surgical procedures and/or loss of the tooth. The free running (FR) pulsed, 3.00 watt (W), FR Nd: YAG; *dLase 300*® dental laser (American Dental Laser™) has been, and is being used by over 500 clinical practitioners worldwide for numerous clinical procedures involving hard tooth structure. This clinical case report involves the use of the FR Nd: YAG laser to assist in the access of a root canal which was obstructed by deposition of calcereous materials (a "calcified canal"). The free running, microsecond pulse ability of the *dLase 300®*, can generate very high power densities (watts/cm^2) in focal spots of 25 to 50 microns. When focused on a small spot of tissue, plasma, which is a gaseous cloud rich in free electrons, suddenly produces an electrical field at the tip of the fiber, in 10^{-2} seconds. This electrical field generates an acoustical shock wave, which carries kinetic--not thermal--shock-wave energy to the target tissue (i.e. "photo-disruption"). The helium-neon (HeNe) aiming beam provided canal *illumination* which allowed for direct operator visualization of the canal space and the obstructing tissue. *Trans-illumination* from the HeNe beam resulted in visual differentiation of canal dentin and calcified tissue. FR, Nd: YAG laser/plasma energy was applied to the visible canal obstruction for less than one second. The result was the photo-disruption of sufficient calcified tissue and canal debris to allow a #10 "K" file to pass by the obstructed area, and to access the canal apex. Conventional modalities were subsequently used to enlarge and fill the disto-buccal canal. In eleven (11) subsequent months of post-operative follow-up, the patient has reported complete absence of any pain or discomfort. Radiographs indicate the healing of all periapical lesions.

7. CONCLUSION

This paper reports the clinical trial of a hard-tissue endodontic procedure using a free running (FR) pulsed, Nd: YAG dental laser, after conventional endodontic techniques failed. Described is a technique using FR, Nd: YAG laser energy to assist in accessing a root canal and the apex obstructed by the deposition of calcereous materials (a "calcified canal"). This paper also discusses the "plasma" effect, canal illumination, and trans-illumination using the helium-neon (HeNe) aiming beam. The 3.00 watt (W), pulsed FR, Nd: YAG; *dLase 300®* dental laser (American Dental Laser™) was successfully used at 20 pulses-per-second (pps) @ 1.75 W to photo-disrupt enough calcified tissue to allow a conventional endodontic file to pass the canal obstruction and access the root apex. This paper reports the short-term success of a clinical trial for removing dystrophic calcification in a root canal using a low-watt, pulsed FR, Nd: YAG laser. This clinical trial achieved the immediate, short-term objective of endodontic hard-tissue removal via photo-disruption. The long term effects of this technique from a technology new to the dental specialty, are not now known. Long-term, controlled scientific and clinical studies are necessary to establish the safety and efficacy of both the helium-neon (HeNe) energy for visualization; and the low watt, pulsed FR, Nd: YAG energy to photo-disrupt the hard calcified tissue within the root canal of a tooth. Research is especially needed to understand the effects of a low-watt, pulsed FR, Nd: YAG laser on the activity of osteoclasts and odontoclasts, and identify any risks for developing external and/or internal resorption after the intra-canal application of pulsed FR, Nd: YAG laser energy. The pulsed FR, Nd: YAG *dLase 300®* dental laser (American Dental Laser™) used as described in this clinical report appears to be a very safe, and very effective technique, offers a very conservative treatment alternative to endodontic surgery or extraction, and is significantly more cost-effective than any existing treatment options.

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