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Cleaning and shaping of root canal systems using erbium lasers

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Cleaning and Shaping of Root Canal Systems Using Erbium Lasers:Two Dimensional Change & Surface Characteristics From Erbium Lasers Used for Root Canal Preparation

by

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THESIS

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I. Introduction and Specific Aims:

Endodontics as a dental specialty is both an art and science. In preparing root canal systems one must consider the complex task of both enlarging and shaping the system as well as disinfection. The literature is replete with instruments and techniques to accomplish this. As technology is developed, the application to endodontics is explored using the scientific method. Dental lasers have been approved by the Food and Drug Administration for tooth preparation to obtain access to root canals; pulpotomy; pulp extirpation; pulpotomy as an adjunct to root canal treatment; root canal debridement and cleaning and root canal preparation including enlargement. The Er:YAG received FDA approval on July 11, 2002 (ErCr:YSGG received approval on January 18, 2002). The application of laser technology in dentistry is relatively new and the laser's role in Endodontics needs further exploration.

A. Specific Aims:

The specific aim of this study is to evaluate the ability of the Er:YAG laser to remove dentin in the root canal system in a predictable fashion and to evaluate its cleaning ability.

II. Review of the Literature

A. Bacteria and Pulpal/Periradicular Pathosis

The biologic objectives for cleaning and shaping of root canals are to eliminate pulp tissue, bacteria and their toxins. The relationship between microorganisms and pulpal/periradicular disease was demonstrated in rats by Kakehashi et al. [1] The dental pulp of normal rats exposed to the oral environment developed necrosis, abscesses and periradicular inflammatory lesions while no pathologic changes were observed in germ free animals.

Sundqvist (1976[2]showed a relationship between bacteria and periradicular lesions. Pulp chambers from traumatized teeth without fractures with and without periapical lesions were examined. It was noted that all teeth that exhibited radiographically detectable periapical lesions had positive cultures while teeth with normal periradicular tissues had negative cultures. Moller (1981) [3]showed the relationship between bacterial infection of the pulp and development of periradicular lesions. No inflammatory lesions were observed when necrotic pulps of monkeys were aseptically sealed. However, periapical lesions were noted after deliberate placement of infected pulp tissue. Infection of the dental pulp is required for formation of periradicular inflammation. Classic early clinical studies showed a mixed flora dominated by anaerobes. (Bergenholtz 1974[4], Sundqvist 1976[2]) Studies of microbial populations in chronic endodontic infections can be characterized as predominately anaerobic and Gram negative. (Sundqvist 1976[2], Farber and Seltzer, 1988)[5] In these polymicrobial endodontic infections, each species

of bacteria may display different virulence factors. Variations in bacteria have also been noted according to area of the canal sampled. The apical areas were dominated by slow growing obligate anaerobes. (Baumgartner and Falkler, 1991)[6]. The coronal portion contained more rapidly growing facultative anaerobes. (Fabricius et al 1982)[7]. Bacterial by-products by themselves are also capable of inducing periradicular pathosis (Schein, 1975[8], Moller et.al., 1981[3]) Elimination of pulp and bacteria is achieved by instrumentation of the root canal space.

B. Instrumentation

Stewart[9], in 1955, described root canal therapy in three phases: chemomechanical preparation, microbial control and obturation. Stewart stated that chemomechanical cleaning of the canal systems is extremely important to the overall success of root canal treatment. Schilder (1974)[10] introduced the concept of "Cleaning and Shaping". Cleaning consists of the removal of organic components, microflora, bacterial by-products, denticles, pulp stones, collagen and any existing root canal filling material or medication from the root canal system. Shaping consists of preparation of the root canal system to accommodate obturation in three dimensions. Conventional techniques involve the use of files, ultrasonic and rotary instruments. Medicaments include irrigants such as sodium hypochlorite and EDTA, and intracanal medicaments such as calcium hydroxide. The mechanical objectives for cleaning and shaping are to remove restrictive dentin and

shape a preparation that is thoroughly cleaned and facilitates obturation in three dimensions. Further, Schilder stated that shapes must be generated that are:

1. Continuously tapered and funnel shaped with the
2. Smallest diameter occurring apically and the largest occurring coronally
3. Flow occurring in all planes while
4. Maintaining the position of the apical opening in its original position and
5. As small as possible consistent the ability to obturate three dimensionally

By fulfilling the mechanical objectives of shaping, the biologic objectives are met at the same time and promote a predictable degree of success (Ruddle, C. J., 2002)[11]. Various methods have been employed using mechanical devices (hand, rotary instrumentation), chemicals (irrigants, chelating agents) and physical methods (sonication, ultrasonics, lasers). (Goodis et al., 1993)[12]

Cleaning and shaping is regarded as one of the most important steps in root canal treatment (Schilder 1974[10], Walton 1976[13] and Ruddle 2002[11]). It consists of removal of tissue both vital and necrotic, dentin and in instances of retreatment gutta percha and possible metallic objects such as posts or separated instruments. Proper preparation of the root canal system permits disinfection by irrigation solutions and medicaments as well as facilitating obturation in three dimensions.

The major purposes of mechanical root canal preparation are the prevention of periradicular disease and the facilitation of healing where disease already exists. This is accomplished by:

- Removal of vital and necrotic tissue from the main root canal(s)
- Creation of sufficient space for irrigation and medication
- Preservation of the integrity and location of the apical anatomy
- Avoidance of iatrogenic damage to the canal system and root structure
- Facilitation of canal filling
- Avoidance of further irritation and/or infection of the periradicular tissues
- Preservation of sound root dentin to allow long-term function of the tooth
- (Hulsman, 2005)[14]

Common techniques for cleaning and shaping include manual preparation, engine driven techniques, ultrasonic devices, and lasers.

As stated previously, Schilder[10] described the five design objectives for root canal preparation. He also described four biologic objectives:

-Confinement of instrumentation to the roots themselves

- No forcing of necrotic debris beyond the apical foramen

- Removal of all tissue from the root canal space

- Creation of sufficient space for intracanal medicaments

Crown-down Shaping Technique (Conventional technique)

Straight-line access is achieved and all canal orifices are located. Stainless steel 0.02 tapered, no. 10 and no. 15 hand files are used to explore the coronal two-thirds of the root canal system. The canal is pre-enlarged with hand instruments or rotary shaping files. When the coronal two thirds has been prepared the apical third is accessed with the small hand files and a glide path to the apical terminus is prepared and patency is established. Canal length should be established with an apex locator and confirmed with a radiograph. The decision can now be made to negotiate and finish the apical third with rotary and/or hand instruments.

Use of these methods in preparing root canal systems generally result in the creation of a smear layer. The smear layer is defined by the American Association of Endodontists' "Glossary of Endodontic Terms" as "a surface film of debris retained on dentin and other surfaces after instrumentation with either rotary instruments or endodontic files; consists of dentin particles, remnants of vital or necrotic pulp tissue, bacterial components and retained irrigant"[15]. The composition of the smear layer has been determined, and researchers have found that it contains organic and inorganic components. The inorganic component consists of dentin debris, (which also contains organic material), and the organic component which consists of proteins, pulpal remnants, blood cells and microorganisms. (McComb and Smith, 1975[16], Mader et al, 1984[17], Czonstkowsky et al., 1990 [18]).

It is generally conceded that the most effective method for smear layer removal for use in endodontics is the use of 17% ethyl diamine tetra acetic acid (EDTA) followed by sodium hypochlorite (NaOCl). (Goldman et al, 1982[19]: Baumgartner and Mader, 1987[20]Baumgartner and Cuenin, 1992[21]). EDTA has a chelating effect and is effective in removing the inorganic portion of the smear layer. Removal of the smear layer results in cleaner dentinal walls and when coupled with the use of a sealer reduces the leakage of bacteria through the root canal system. (Clark-Holke, et al., 2003[22])

Studies have shown that lasers are helpful in removing smear layer, tissue remnants and aid the in reduction of microorganisms. In addition, laser may modify the root canal dentin through melting and resolidification and reduce dentin permeability. (Stabholz, et al, 1993[23], Goodis et al., 1993[12])

C. Lasers

1. Development and Uses

A laser is a device that creates and amplifies a narrow beam of coherent light. First constructed in 1960, lasers are now as small as salt grains (semiconductor lasers) or as large as buildings (solid state and gas lasers). Lasers are commonly employed in industrial uses for cutting and boring materials, in medicine for surgery as well serving functions in communications and research. Lasers are also commonly found in audio and

video components, military weapons and supermarket scanners. Many medical specialists employ different lasers daily in their respective practices.

Lasers have been in clinical use for many years. The CO_2 laser is commonly used for soft tissue and oral surgery. The Nd:YAG laser is also used for intraoral soft tissue surgery. In 1991, the Argon laser came into use for light curing of composite restorations. In 1998, the Er;YAG and ErCr:YSGG lasers came into use for caries removal and cavity preparation.

In 1917 Albert Einstein[24] published mathematic proof showing that portions of the electromagnetic spectrum could be stimulated to produce amplified light. It was until the 1950's that Charles H. Townes amplified microwave frequencies by stimulated emission with what became known as the MASER (Microwave Amplification by Stimulated Emission of Radiation)(Gordon, 1954)[25]. Schawlow and Townes (1958)[26] suggested applying the MASER principles to the optical range of the electromagnetic spectrum. In 1960 Maiman[27] inserted a ruby rod into a photographic flash to produce a LASER (Light amplification by Stimulated Emission of Radiation).

Niels Bohr[28] hypothesized that atoms can exist in multiple energy states and when they change states, there is an absorption or emission of a quantum of light energy, a photon. In absorption a photon is picked up and the atom is raised to a higher energy state. Alternately, in emission, a photon of energy is released as the atom drops to a lower energy state. Photon emission may occur spontaneously or via stimulation of atoms. In

stimulation, there is a release of two photons of energy that add to each other (light amplication). Most active media are kept in higher energy states inducing a population inversion. An optical resonator is used to provide additional amplification of the stimulated light until a level is reached where all additional energy in the cavity is used to maintain laser output. This closed system produces a coherent, monochromatic, and collimated light. Laser light is one wave length that travels in phase both temporally and spatially and coherently (in the same direction), neither converging or diverging. This is very different from ordinary light that radiates in all directions with incoherent waves and many wavelengths. Final properties of laser energy are that it is composed of light at a single wavelength, travels in one direction and is monochromatic while ordinary light is usually composed of numerous wavelengths and colors traveling in all directions.

2. Design and Components

Most lasers consist of three basic components. First is the material that is stimulated to emit light called the active medium. The laser is usually named for its active medium. The medium may be in the form of atoms or molecules in a solid, liquid or gaseous state or in an electronic state (such as a series of capacitors arranged in a diode array). Second is the pumping mechanism that provides the stimulation. Third is the optical resonator that produces the majority of the laser's unique characteristics. The active medium for an Er:YAG laser is the element Erbium in a yttrium-aluminum-garnet crystal.

3. Laser-Tissue Interaction

Laser tissue effects have been investigated in dentistry since the first lasers were developed. In the1960's Stern and Sonnaes[29], Goldman[30], and Lobene [31]focused on dentin laser tissue interactions. It has been shown that surface modifications to dentin by laser treatment resulted in increased microhardness. (White et al, 1996)[32]. In addition, partial closure of dentinal tubules by laser treatment alters fluid flow in dentin although total impermeability has not been shown. (Goodis, et al, 1992)[12]. Further research may lead to methods to decrease microleakage.

Early researchers used continuous wave devices with long interaction times and non-contact delivery of energy. These studies resulted in detrimental thermal effects, burning and carbonization of the dentin surface, melting, creation of fissures, cracks in the surrounding hard tissues and increased pulpal temperatures. This was due to the relatively long interaction time with the substrate. (Featherstone, 1987[33], Wigdor, 1993[34], 1995[35]

The interaction of laser and tissue is determined by the laser irradiation parameters and the tissue characteristics that determine absorption. These are the wavelengths, the repetition rate, the pulse energy and the absorption characteristics of the target tissue or tissues. The optical properties of the target tissue are determined by the refraction index, scattering of light and the absorption coefficients. The effect of laser energy on tissue is directly dependent on the energy concentrated in the target tissue. Laser-tissue interactions in dentistry are photothermal events. Temperature increase is the main

determinant in evaluating changes in morphology and chemical structure of the target tissue.

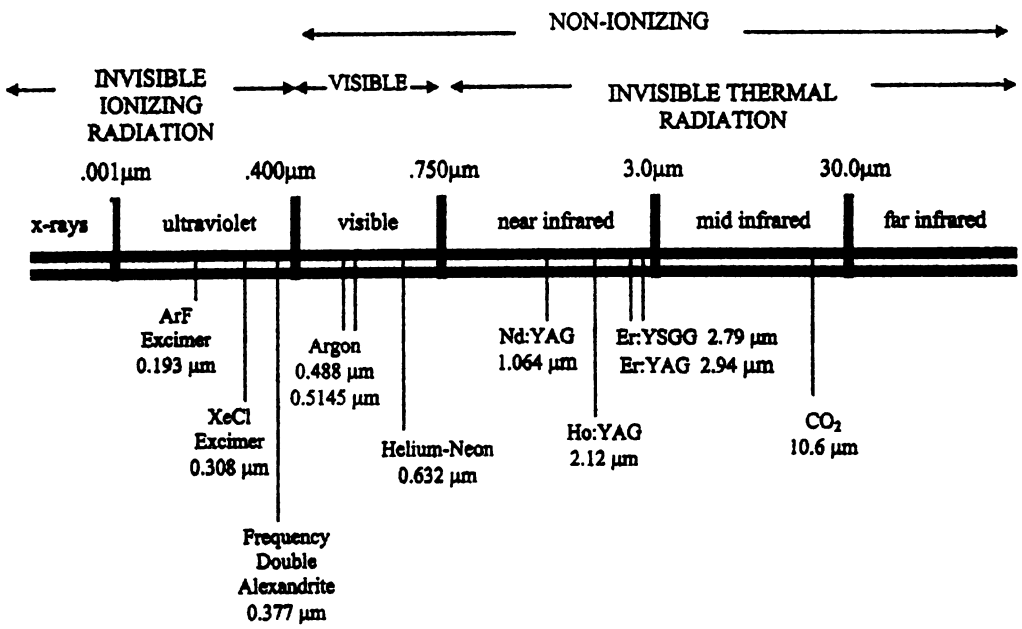


Figure 1. The diagram illustrates a portion of the electromagnetic spectrum as well as the lasers of interest in dentistry (Technologies, 2000)[36]

Erbium lasers are absorbed well both in water and water within the hydroxyapatite crystal. This makes them especially suited for cutting enamel, dentin, bone and soft tissue. Lasers that emit in the ultra violet, visible and near infrared light range (e.g. argon 0.488 μm and 0.5145 μm and Nd:YAG 1.064 μm) are not absorbed well by enamel and dentin. Argon lasers are better used on pigmented or vascularized tissue. The Nd:YAG laser also functions well on pigmented tissue (such as granulation tissue) and is not as

well absorbed by water. Excimer lasers (193, 248 and 308 μm) are also absorbed well by enamel and dentin. CO_2 lasers which emit in the mid-infrared range were some of the first lasers used to cut dental hard tissue. The CO_2 laser works best on tissue having high water content and is also well absorbed by hydroxyapatite.

Technologic advances occurring within the last 15 years have made the delivery of laser energy through fibers more practical for dental use. Laser fibers and tips can be small allowing precise delivery. In addition to improved delivery, lasers have been made which have microsecond pulse duration. These free running solidstate microsecond pulse duration lasers have overcome the adverse heat effects of earlier continuous and long pulse laser systems.

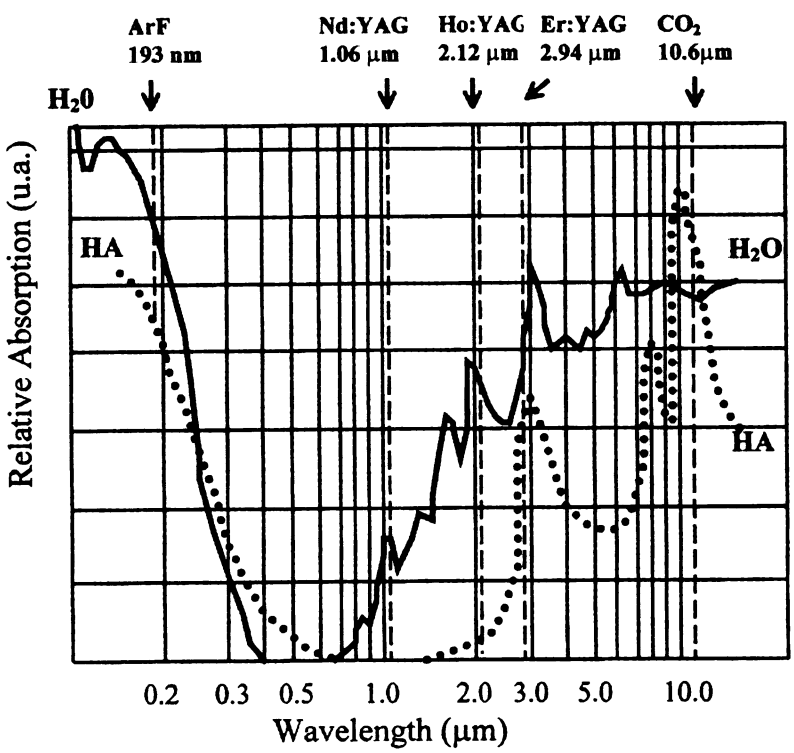


Figure 2. Water and hydroxyapatite absorption spectrum. (Frentzen, 1992)[37]

4. Lasers in Dentistry

Lasers used in dentistry fall into the non-ionizing, infrared and visible ranges of the electromagnetic spectrum. When used in dentistry, these lasers effect an increase in temperature on the target tissue. This temperature increase can coagulate, vaporize or carbonize tissue. Examples of lasers in use from the infrared range are the Nd:YAG(1.064μm), the Ho:YAG(2.12μm), the Er:YSGG(2.79μm), Er:YAG(2.94μm)) and the CO_2(10.6μm). In the visible light range are the Helium-neon (0.632μm) and the argon laser (0.488μm and 0.5145μm).

5. Lasers in Endodontics

The use of lasers in endodontics dates to the works of Weichman and Johnson in 1971[38]. A preliminary study was performed to externally seal the root canal at the apex using a Nd:YAG and a CO_2 laser. Their attempts were not successful but provided data of some use. Wiechman et. al. (1972)[39] discussed physical and chemical changes of laser treated dentin. Early researchers were interested in trying to seal apical foramina using lasers. These investigations also were not successful due to the adverse heat effects of continuous wave lasers available at the time. It is conceivable that with material development (thermoplastics) that apical foramina can be sealed but it is unlikely that any laser device will melt dentin and have it re-solidify to seal the apex. Stabholz (2004) [40]defined three main areas in endodontics for the use of lasers: 1) the periapex, 2) the root canal system and 3) the hard tissue (dentin). The effect of different types of laser

energy on root canals has been investigated- the CO_2 laser (Zakariasen et al., 1986)[41], the Nd:YAG laser (Goodis, 1993)[12], the argon laser the Er:YAG and the ErCr:YSGG

The Nd:YAG, argon, excimer, holmium and erbium beams are delivered via optical fiber whereas the CO_2 is delivered via a waveguide (mirror) articulated arm. The optical fiber permits better accessibility to intraoral structures through contact with object tissue. Virtually all endodontics carried out with lasers require initial enlargement of the canal space to permit introduction of the optical fiber. Optical fibers can be as small as 200 microns, which is equivalent to a #20 file.

The first use of lasers in root canal preparation was in 1984 (Dederich et al)[42]. A Nd:YAG laser was used to irradiate root canal walls. The results demonstrated melted, recrystallized and glazed surfaces. Many studies since then have shown the laser's effectiveness in cleaning of root canal systems. Levy (1992)[43] and Goodis (1993) [12]used an Nd:YAG laser in combination with hand instruments and produced a cleaner root canal system without a smear layer.

In the 1990's, dental lasers were developed with short pulse durations (microsecond), high peak power, fiberoptic delivery systems, with air/water coolants which allow for the ablation of enamel and dentin and accurate delivery in the oral cavity. Most recently, with the advent of smaller fiberoptics, the ability of lasers to remove dentin within the root canal system has been realized. The US FDA granted marketing clearance for

Erbium lasers for enamel and dentin removal (ablation) (1990's), and in 2002 the FDA granted clearance for Erbium lasers for root canal treatment.

6. Bacterial reduction by lasers

An important rationale in using lasers in endodontic treatment is microbial reduction. This is usually achieved through temperature rise. The removal of debris by laser irradiation also results in less bacteria in the root canal system. Microsecond pulse duration lasers have high peak power and low average power. Laser light, when absorbed by tissue, heats the tissue to temperatures far in excess of their melting point, causing vaporization. At these temperatures of over 1,200 C, bacteria are also removed.

7. Thermal Effects

Thermal effects of laser treatment are a principle concern in endodontic treatment using lasers. The main concern is the heat produced at the root surface at its effect on the surrounding tissues. Hibst et al. (1997)[44] showed that use of a highly absorbed laser light, (eg Er lasers) localize the heating to a thin layer at the surface of the target tissue which minimizes the absorption depth. Therefore there was a decrease in the risk for subsurface thermal damage as less energy is required to heat the surface. Koba et al. (1998[45], 1999[46]) studied changes at the apical constriction and performed histological analyses of periapical tissues after laser treatment. In these studies the optical fiber was kept in the same position at 1 mm from the apical foramen for two to three seconds. Inflammatory cells were observed in all groups, including the control at two weeks. The degree of inflammation in the lasers group at two weeks was found to be

significantly less than in the control at 4 weeks and 8 weeks. The same authors also demonstrated the possibility of inducing carbonization depending on the laser operating parameters. Kimura et al 2002[47]measured the temperature of the root surface during Er:YAG laser irradiation to prepare root canals and found the effect on periodontal tissues to be minimal.

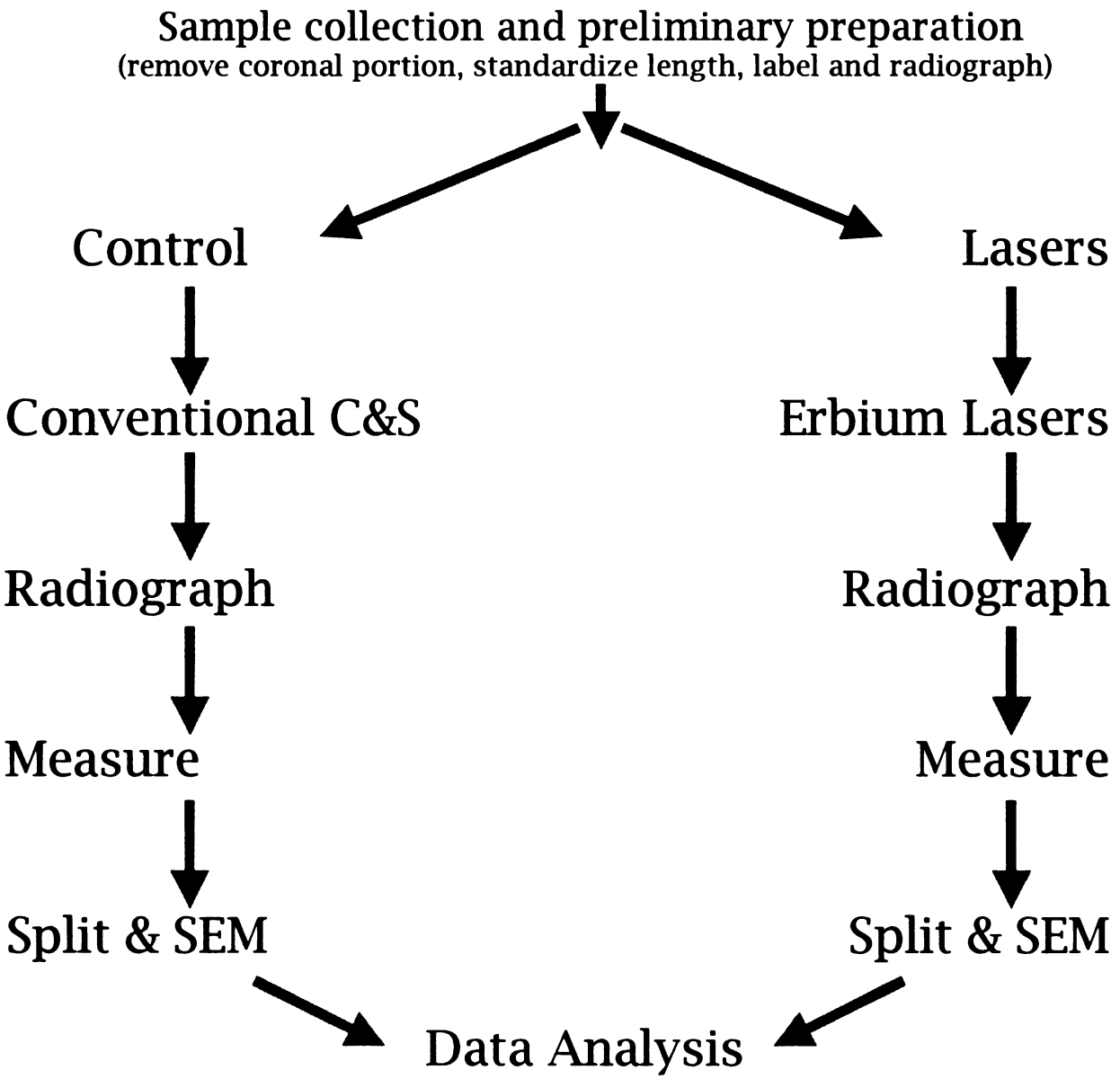
Use of Er:YAG lasers in endodontics has been proposed and several preliminary studies have been performed. Matsuoka et al.2005, [48] found that root canal walls treated with an Er:YAG laser were scale-like and clean but rough and irregular when evaluated via FE-SEM. Kimura et al measured the temperature of the root surface during Er:YAG laser irradiation to prepare root canals and found the effect on periodontal tissues to be minimal. In another study, Kimura [49]concluded that canal preparation by Er:YAG laser does not effect apical leakage compared to conventional cleaning and shaping. Perin et al[50] compared the antimicrobial ability of 1% NaOCl with conventional instrumentation to use of the Er:YAG laser and noted that both were effective against the selected organisms. Kesler et al [51], in a histological study and SEM study of root canals treated with the Er:YAG laser noted that the Er:YAG laser special microprobes are effective in shaping, cleaning, and enlarging straight root canals faster and more efficiently then traditional methods. Ali et al. (2005)[52] compared the ability of the ErCr: YSGG laser in removing smear layer and debris with conventional hand instrumentation. While a significant decrease in smear layer and debris was noted in the laser groups, there were also numerous incidents of ledging, zipping and over-instrumentation.

Hypothesis:

Erbium lasers can clean and shape straight root canal systems in a predictable fashion and in a manner similar to step-back/crown-down hand techniques

Figure 3.

EXPERIMENTAL FLOW CHART



A. Shaping

The research was conducted under the protocols of the Committee on Human Research (IRB) at the University of California at San Francisco; exempt status was obtained for the collection of teeth. Sample size estimates based on the following assumptions: $\alpha = 0.05$, power = 0.8, and assuming a minimum detection difference of 20% and a standard deviation of 15% yielded a sample size of fourteen.

The study was carried out on 28 single-rooted extracted canine, maxillary central incisor and lower first bicuspid teeth with straight roots as ascertained by radiographs. The teeth were sterilized by gamma radiation (White, 1994)[53] and radiographed from mesio-distal and bucco-lingual directions using a digital radiograph system (TrophyMac, Trex-Trophy Radiology Inc. Marne-la Valle'e, France). The coronal portions were removed with a water-cooled diamond saw and diamond disc (Diamond Wafering Blade, Buehler Ltd, Lake Bluff, Illinois, USA) to standardize the specimens to a 15 mm length. The specimens were ground flat using a water-cooled model trimmer (Buffalo Dental Manufacturing, Syosset, NY, USA) on two non-opposing sides without encroaching on the root canal space in order to reproduce their orientation in radiographs.

Endodontic access was achieved, if needed, with a number 2 round bur using a highspeed handpiece. Length verification was obtained with hand files to the apical opening. The working length was established at the apical foramen. A #25 hand file was the last instrument in all cases in order to standardize the size of the apical foramen.

The teeth were randomly divided into two groups of fourteen teeth each. The first group was cleaned and shaped by enlarging to a #25 ISO K-file to the apical foramen, using the crown-down technique with GT NiTi rotary files .10 taper to .04 taper (Tulsa Dentsply, Tulsa, OK, USA), finished with a GT .10, irrigated with 5 ml of sodium hypochlorite and treated with 17% EDTA for 30 seconds. This group served as the control group. Group Two used the Er:YAG laser. The laser group was prepared with microprobes 200 to 400 micrometers in diameter and 31 mm in length attached to special delivery handpieces. The ErYAG laser (Delight laser, HOYA- CONBIO, San Jose, CA) was applied using the following parameters: wavelength 2.94 micrometers, 400 msec pulse duration, 20Hz repetition rate and 250mJ energy per pulse. The microprobes were employed in a crown down fashion using a pecking motion to place and retrieve the microprobe while working around the canal in a clockwise fashion. In this manner a portion of the canal wall was treated and the microprobe was then retrieved and moved to the next position in the simulated clock face motion. All of the procedures were timed for comparison to control.

The area removed was calculated by evaluation of preoperative and postoperative digital radiographs and image analysis using Image J analysis software (Abramoff)[54]. Teeth from each group were sagitally sectioned using a water-cooled diamond saw (Isomet, Beuhler Ltd., Lake Bluff, IL, USA) and examined using a scanning electron microscope for examination of smear layer removal and condition of the canal walls. Examination of surface characteristics was performed under Charge Free Atmospheric System (CFAS) at 750x magnification. (ISI/TOPCON SX40A1, International Scientific Instruments,

Pleasanton, CA). All endodontic instrumentation was completed by the same operator (M. J. R.).

B. Cleaning

A separate group of three teeth were evaluated for cleaning effects using an Er:YAG laser with specially designed spiral tips. These teeth were treated by enlarging to a #25 ISO K-file, using the crown-down technique with GT NiTi rotary files .10 taper to .04 taper (Tulsa Dentsply, Tulsa, OK, USA), finished with a GT .10 taper and irrigated with 5 ml of sodium hypochlorite. The teeth in this group were treated with 1 cc of 17% EDTA (Roydent) and lased using a spiral tip for 30 seconds at 15 pulses per second at 700 mjoules per pulse (OPUSDent, Netanya Israel), rinsed with another 1 cc of 17% EDTA. This was followed by a second rinse using 5cc de-ionized water. The teeth were stored in de-ionized water. These teeth were sagitally sectioned using a water-cooled diamond saw (Isomet, Beuhler Ltd., Lake Bluff, IL, USA) and surface characteristics were examined under Charge Free Atmospheric System (CFAS) SEM at 750X. (ISI/TOPCON SX40A1, International Scientific Instruments, Pleasanton, CA)

C. Energy Density Calculations

Energy density was calculated by recording the output from the tips as measured in watts (W) using a light meter (Ophir Optronics, Wilmington, MA, USA). The laser was activated at the appropriate settings and the fiber optic probe held over the meter until a stable reading was obtained. The output from the tips was averaged in the 250 mj

category and used in the following calculation. The probes were photographed and the size of the probes was measured using a measuring microscope and found to be within 2 micrometers of the specified size by the manufacturer for all tips used. The probes were photographed using the Olympic BX50 light microscope (Olympus Corp., Tokyo, Japan). The image was captured with XCAP-Lite for Windows version 2.2030227 (EPIX Inc, Buffalo Grove,IL, USA) and analyzed with Image-Pro Plus for Windows version 4.5.1.29 (Media Cybernetics Inc., www.mediacy.com).

W/Hz = Joules (J) and Energy Density = J/cm^2

Energy Density for the 200 micrometer probe at 20 Hz and 250 mJ per pulse was calculated to be 58.9 J/cm^2

Energy Density for the 300 micrometer probe at 20 Hz and 250 mJ per pulse was calculated to be 81.43 J/cm^2

Energy Density for the 400 micrometer probe at 20 Hz and 250 mJ per pulse was calculated to be 112.7 J/cm^2

Table 1. Energy in Watts; 200 micrometer probe 10 Hz

	50mJ	100mJ	150mJ	200mJ	250mJ
10 Hz					
1	0.06	0.12	0.19	0.25	0.35
2	0.08	0.15	0.23	0.30	0.35
3	0.09	0.17	0.25	0.33	0.39
4	0.08	0.16	0.25	0.32	0.38

Table 2. Energy in Watts; 200 micrometer probe, 20 Hz

	50mJ	100mJ	150mJ	200mJ	250mJ
20 Hz					
1	0.11	.024	0.38	0.48	0.57
2	0.13	0.28	0.39	0.53	0.59
3	0.13	0.28	0.41	0.55	0.67
4	0.13	0.27	0.41	0.52	0.66

Table 3. Energy in Watts; 300 micrometer probe, 10 Hz

	50mJ	100mJ	150mJ	200mJ	250mJ
10 Hz					
1	0.12	0.24	0.38	0.53	0.63
2	0.10	0.20	0.33	0.45	0.53
3	0.14	0.28	0.44	0.59	0.79
4	0.15	0.30	0.47	0.61	0.75

Table 4. Energy in Watts; 300 micrometer probe, 20 Hz

	50mJ	100mJ	150mJ	200mJ	250mJ
20 Hz					
1	0.26	0.48	0.72	0.89	1.05
2	0.18	0.38	0.59	0.75	0.95
3	0.26	0.53	0.80	1.04	1.28
4	0.28	0.54	0.82	1.05	1.28

Table 5. Energy in Watts; 400 micrometer probe, 10 Hz

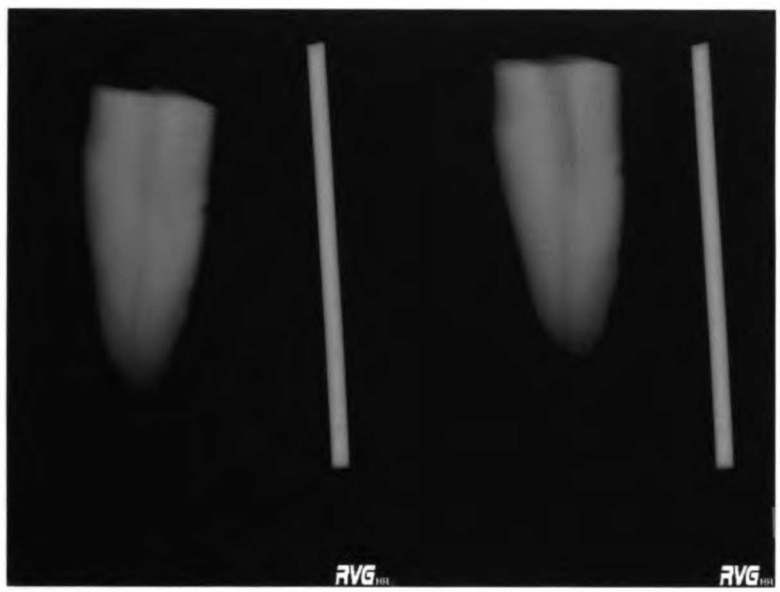
	50mJ	100mJ	150mJ	200mJ	250mJ
10 Hz					
1	0.23	0.55	0.85	1.07	1.43
2	0.33	0.63	0.94	1.26	1.56
3	0.31	0.65	0.99	1.32	1.67
4	0.28	0.66	0.97	1.31	1.53

Table 6. Energy in Watts; 400 micrometer probe, 20 Hz

	50mJ	100mJ	150mJ	200mJ	250mJ
20 Hz					
1	0.50	1.04	1.62	2.15	2.48
2	0.55	1.17	1.67	2.26	2.84
3	0.56	1.20	1.81	2.39	3.04
4	0.58	1.16	1.81	2.41	2.97

D. Data Analysis

Results were analyzed using ANOVA. Dependant variables were: width of canal (shaping) in coronal middle and apical thirds and in total and time of shaping. Data analysis was performed using Prism statistical software (Graph Pad Software, SanDiego, CA, USA).



Before After

Figure 4. Example of laser shaping

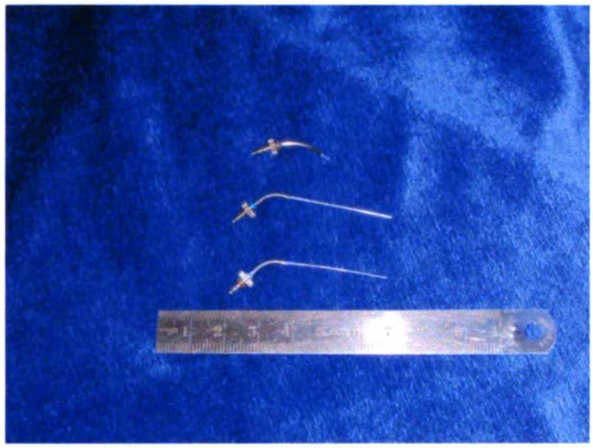


Figure 5. Fiberoptic tips from top to bottom 400 micron, 300 micron and 200 micron sizes

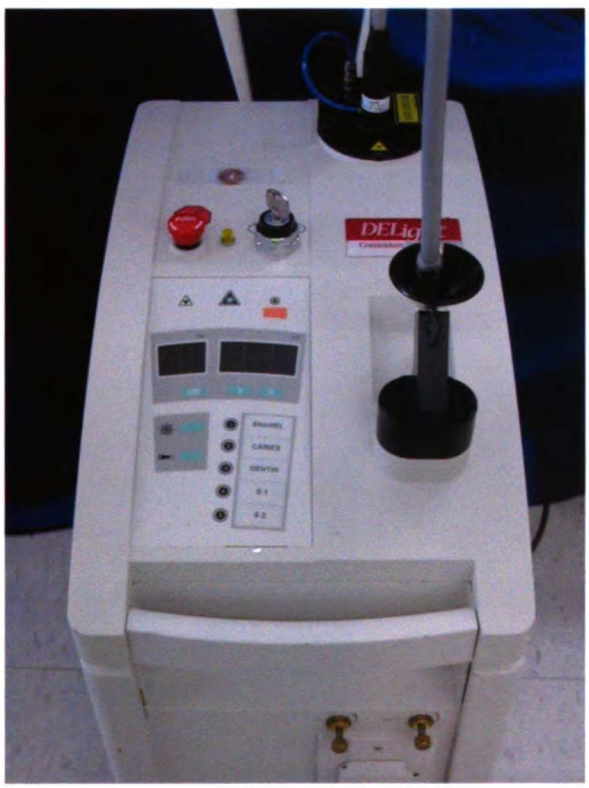


Figure 6. Hoya CONBIO Er:YAG Laser

Figure 7. 200 micrometer tip

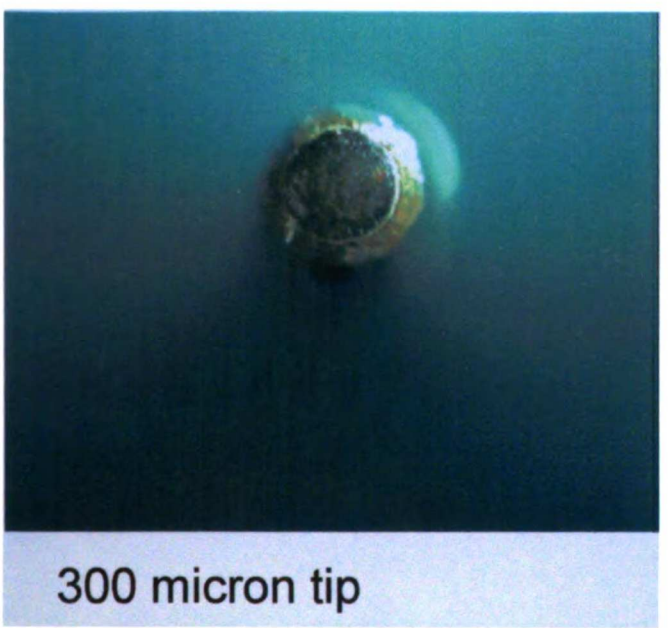


Figure 8. 300 micrometer tip

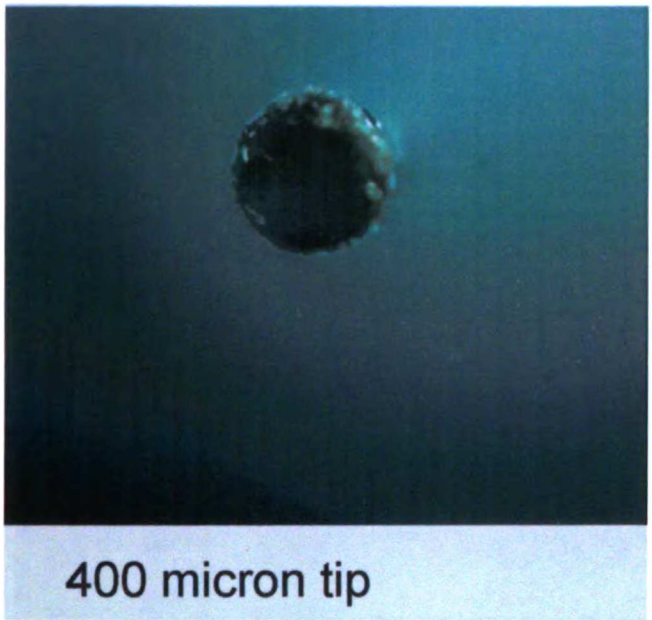


Figure 9. 400 micrometer tip

IV. Results

Analysis of the amount of dentin removed was calculated by subtracting the before measurement from the after measurement in both mesial-distal and buccal lingual directions. The Er:YAG laser removed significantly more dentin in the coronal third compared to the rotary files. However, the rotary files removed significantly more dentin in the mid and apical thirds. Analysis by two way ANOVA demonstrated significant differences at all three levels ($p<0.0001$) (fig 10, 11,12 and 13)

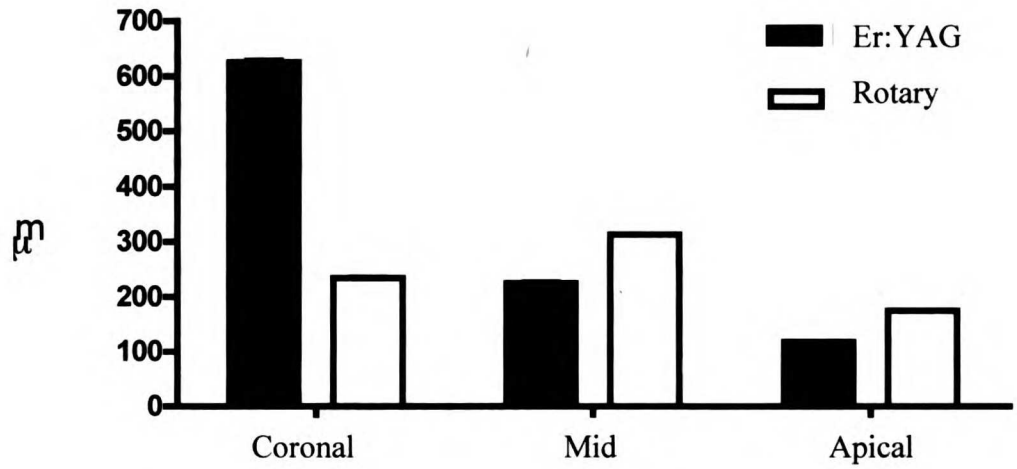


Figure 10. Dentin removal all three levels, Er:YAG vs Rotary

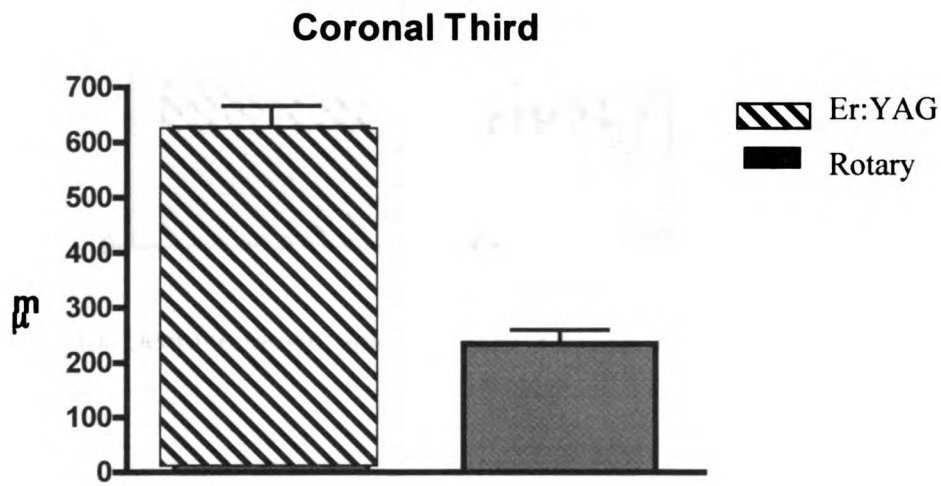


Figure 11. Dentin removal in Coronal third, Er:YAG vs Rotary

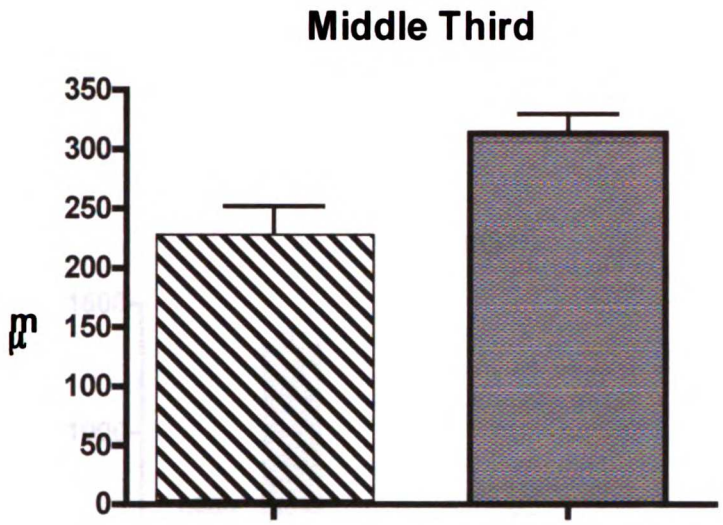


Figure 12. Dentin removal, middle third Er:YAG vs. Rotary

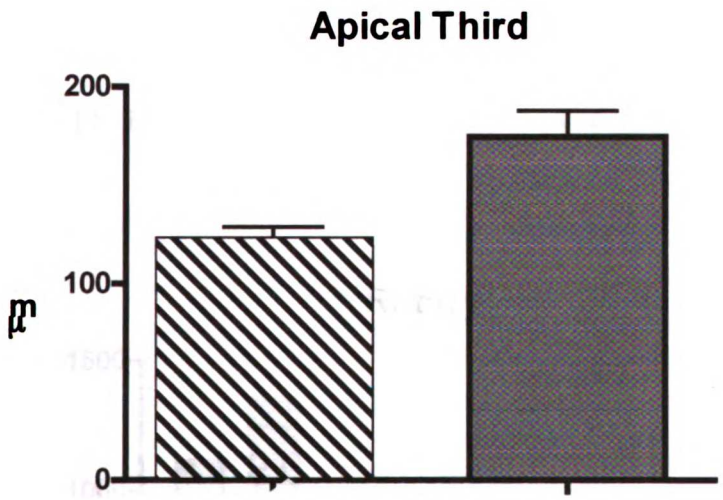


Figure 13. Dentin removal, apical third Er:YAG vs. Rotary

Analysis using t-test within the respective groups showed a significant amount of dentin removed by both techniques ($p<0.05$) (GT rotary files and laser) at all three levels. (figures 14 and 15)

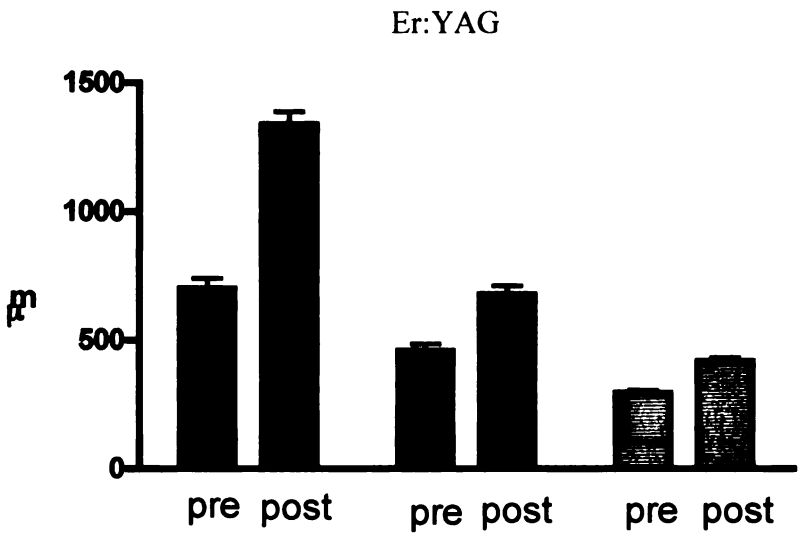


Figure 14. Er:YAG Pre and past treatment canal measurements

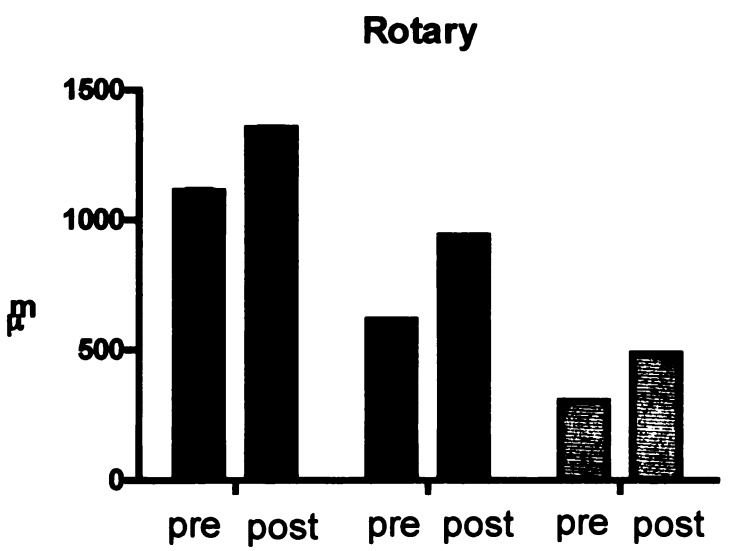


Figure 15. Rotary pre and post treatment canal measurements

When time of preparation was examined it was determined that the laser group required significantly longer preparation than the GT rotary file group. ($p<0.05$) On examination of the average time, the laser group took almost twice as long as the conventional method. (figure 16)

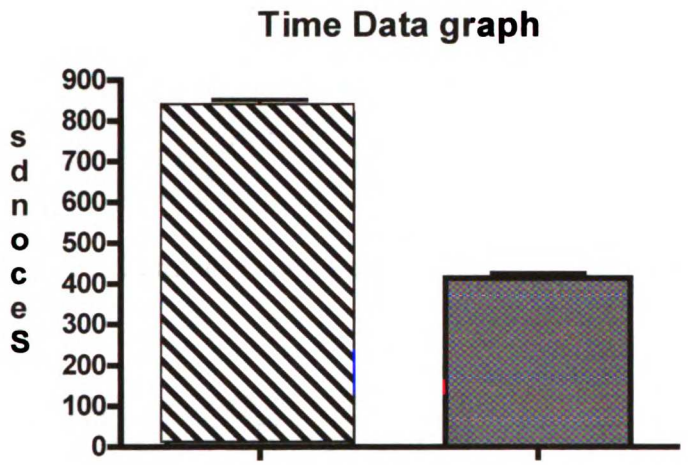


Figure 16.

SEM Results

Scanning electron microscopy of the samples was performed at all three levels in the three groups (Rotary (control), Er:YAG laser and Er:YAG laser with spiral tip). In the rotary group, all three levels displayed clean, open tubules with some amount of debris remaining. The mid-section (figure 18) appeared the cleanest of all levels followed by the coronal (figure 17) and apical section (figure 19).

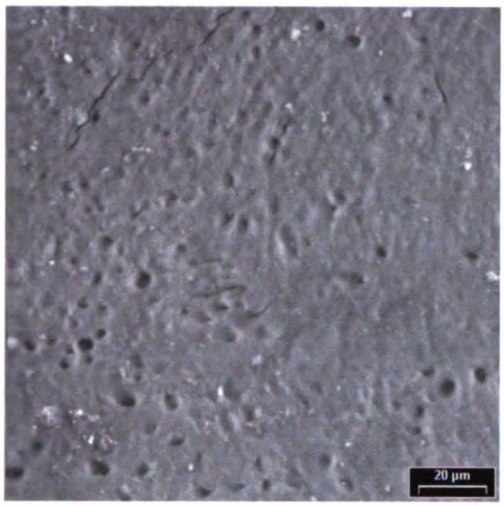


Figure 17. Coronal section Rotary Group

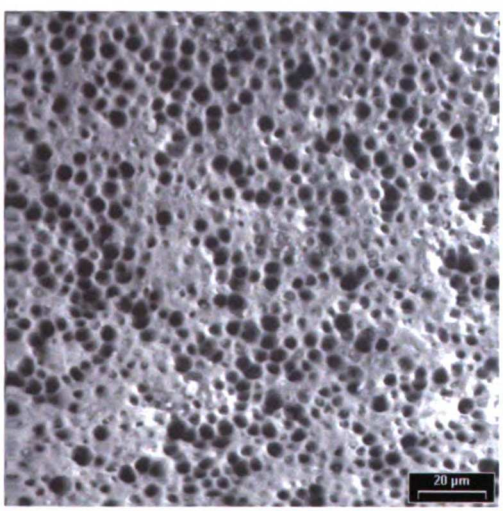


Figure 18. Mid section Rotary Group

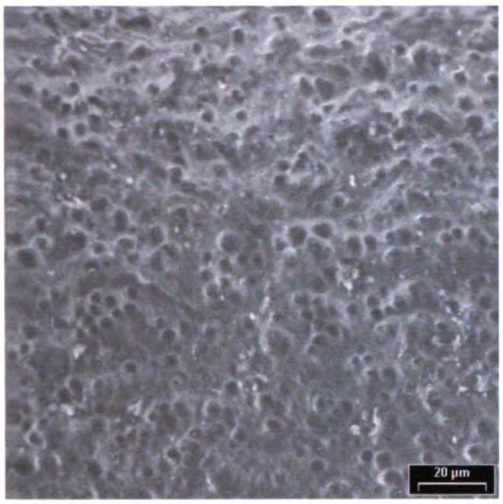


Figure 19. Apical section Rotary Group

Er:YAG Group

The surfaces appeared altered and irregular at all levels. The appearance of dentinal tubules was not noted with any regularity at any level in the laser group. A dense smear layer and debris were noted on the surfaces of the root canal systems treated with the Er:YAG laser.

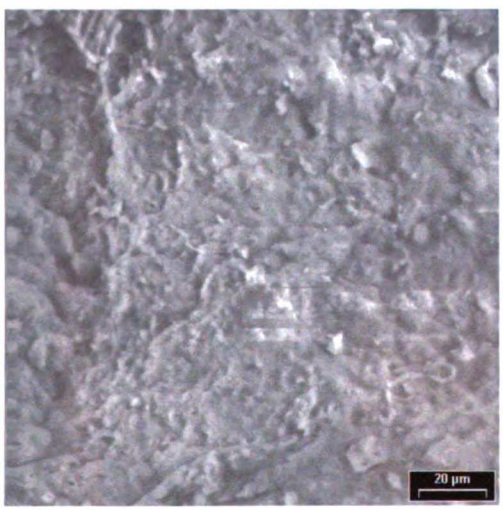


Figure 20. Coronal section Er:YAG Laser Group

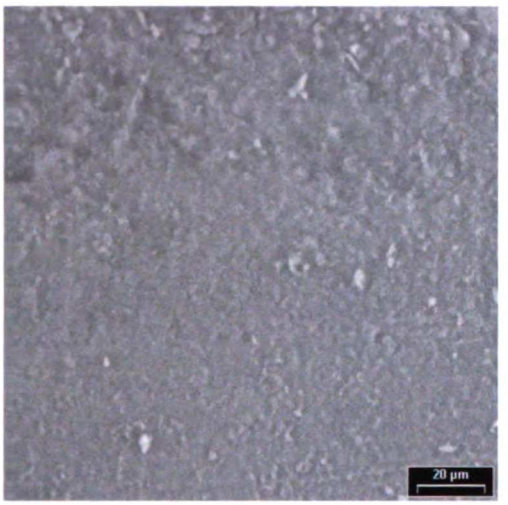


Figure 21. Mid section Er:YAG Laser Group

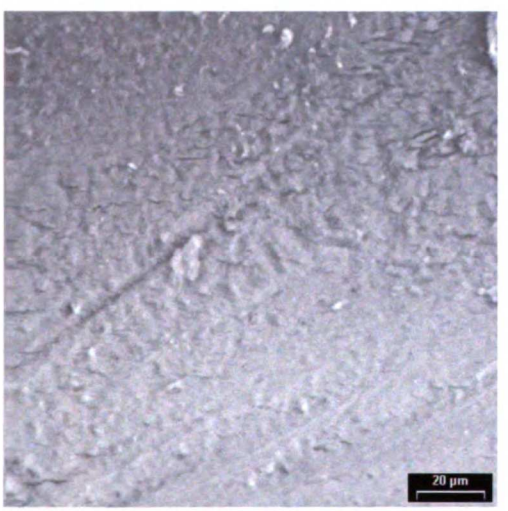


Figure 22. Apical section Er:YAG Laser Group

The Er:YAG Laser with Spiral tip Group

The coronal portion appears partially clean (figure 23). The tubules remain somewhat occluded. The mid and apical sections (figures 24 and 25) exhibit a dense smear layer and debris. The Er:YAG laser had a minimal effect if any in the mid and apical sections in removing the smear layer.

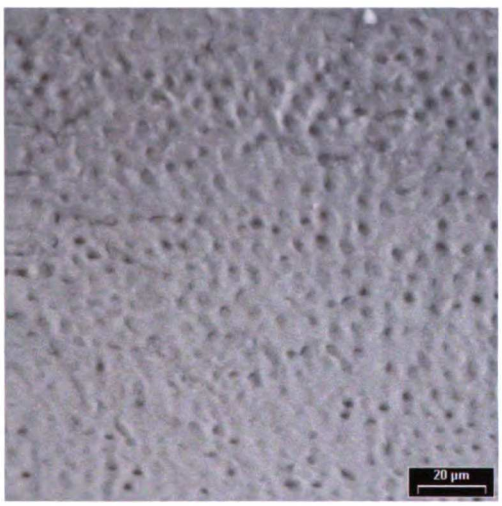


Figure 23. Coronal section Er:YAG Laser with Spiral Tip Group

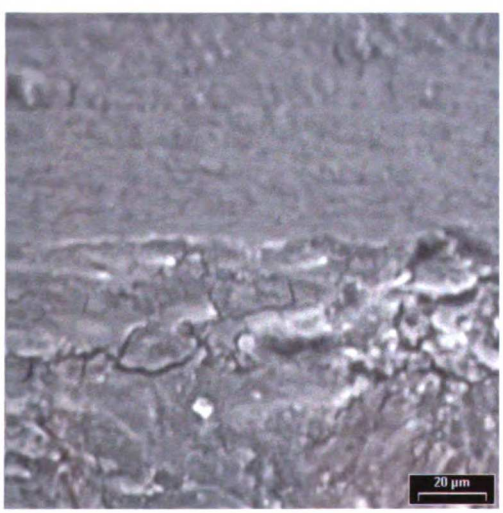


Figure 24. Mid section Er:YAG Laser with Spiral Tip Group

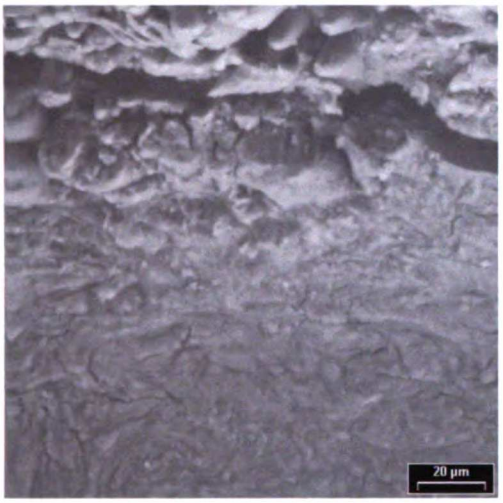


Figure 25. Apical section Er:YAG Laser with Spiral Tip Group

V. Discussion

The use of the Er:YAG laser with water spray to ablate dental hard tissues has been explored using extracted teeth (Visuri et al , 1996)[55]. The laser has also been shown to be effective and practical for cavity preparation in vivo (Matsumoto, 1996)[56]. Treatment of enamel and dentin with the Er:YAG laser has been shown to increase resistance to acid attack (Hossain et al, 2000)[57]. Laser irradiated dentin has been shown to have an increased microhardness (White, 1996)[32]. The use of the Er:YAG laser in root canal treatment has been shown to kill bacteria within the root canal system (Jelinkova et al 1999)[58]. The mechanical objectives in root canal cleaning and shaping are to remove the organic components, microflora, bacterial by-products, denticles, pulp stones and collagen. Shaping consists of preparing the root canal to accommodate obturation in three dimensions. The control specimens consistently met the objectives for cleaning and shaping. The protocol in this experiment produced relatively clean control preparations without smear layer and small amounts of debris. The cleanest portion was the mid level followed by the coronal and then the apical portion. The control specimens exhibited a smooth tapering, conical shape widest at the coronal and narrowest at the apex. The shapes achieved using the laser were quite wide in the coronal portion and narrower than the control in the mid-root and apical portions. This produced a much narrower preparation and less than ideal taper compared to the control. The laser shapes did not exhibit the "flow" of the control preparations. This may have been due to the inexperience of the operator in shaping root canal systems using the Er:YAG laser. Before and after image analysis demonstrated that the laser removed significantly more

dentin than the control group in the coronal section. However, the control protocol removed significantly more dentin in the mid and apical portions.

The exact mechanism of ablation of dentin by the Er:YAG laser has not been determined. It is thought that irradiation by Er:YAG laser may induce vaporization and microexplosion of water. Upon examination both in measurement and via SEM it was obvious that laser removal of dentin had occurred. The measurements consistently demonstrated significant dentin removal at all levels in both groups and SEM examination revealed an altered dentin structure within the root canal system in the Er:YAG group. The dentin surface appeared altered and irregular. The appearance of dentinal tubules was not noted with any regularity at any level in the laser group. A dense smear layer was noted on the surfaces of the root canal systems treated with the Er:YAG laser. Color changes that may be indicators of carbonization, charring or burning were not detected on visual or stereoscopic exam after sectioning.

In developing the technique to measure the dentin removed care was taken to be able to duplicate the identical tooth position in relation to the radiograph. Each specimen was ground flat on two sides without encroaching on the canal space. This enabled exact duplication of the canal image in both before and after radiographs. Calibrations of measurements against a known were made in each radiograph. The ImageJ software permitted consistently reproducible measurements of less than 100 micrometers.

The objective in studies on post-treatment shape is to assess the conicity, taper, flow and preservation of the original canal shape and curvatures. Evaluations include the degree and frequency of straightening, ledging, transportation etc. The control protocol produced more ideal, predictable shapes than the Er:YAG laser in less time. Analysis of the data showed a significant difference in preparation time between the two groups. The goal in evaluating working time is to reach a conclusion regarding the efficacy of the technique and its clinical significance. Preparation of root canal systems using the laser required on average almost twice the preparation time of the controls. Even though this study limited its' scope to straight canals there were several procedural errors noted in the Er:YAG laser group. These consisted of over enlarging the coronal section and apical perforations or transportation of the apex. The issue of over enlarging the coronal portion may be resolved with more experience with laser cleaning and shaping. The issues of apical perforation or transportation may be resolved by creation of a better glide path for the laser probe to follow. This may be as simple as modifying the 400 micron probe to extend further into the root canal system to permit better enlargement of the mid section or by using more hand instrumentation. This would allow the probe to ablate or bypass any irregularities in the canal system that may divert the smaller 200 micrometer probes.

The energy density of the 200 micrometer probe was calculated to be close to the minimum ablation threshold for dentin. Fabrication of a larger probe, 35 micrometers, may also facilitate shaping by supplying a higher energy density and consequently more efficient removal of dentin.

The Opus spiral tip portion of the study showed results inconsistent with previously published studies. The coronal portion appeared somewhat clean. There was no debris noted but tubules remained partially occluded. In the mid and apical portions the tubules were not visible. Large amounts of smear layer remained. It is conceivable that the tip displaced the EDTA solution in the mid and apical portions of the canal upon placement into the root canal space. Little if any effect was noted in the mid and apical sections.

Root canal treatment with Er:YAG lasers may eventually prove successful. Numerous anatomical and histological studies have detailed the intricate and complex characteristics of the root canal system. These include variations in canal number, shape, size and curvature. The complexity of the root canal system should be considered as one of the major tests in preparing root canal systems. Advantages of laser endodontics include smear layer removal (not demonstrated here), bacteriocidal effects, and increased microhardness of dentin. However, this system has difficulties in producing ideal shapes for obturation and may induce procedural errors. Current technology appears impossible to use successfully in curved canals.

Further studies focused on shaping and eliminating procedural errors are required before root canal treatment using Er:YAG lasers can be applied successfully in a clinical setting.

VI. Conclusions

1. The control group produced cleaner, more ideal shaped root canals in less time than the Er:YAG laser group.
2. The Er:YAG laser group removed more dentin in the coronal portion but less dentin in the mid and apical thirds of the canals.
3. The Er:YAG Laser with Spiral Tip group left a dense smear layer in the mid and apical thirds. The coronal portion did not appear as clean as the control group.
4. The Er:YAG laser group was subject to procedural errors more often than the control group.

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