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ORIGINAL RESEARCH

Temperature Rise on External Root Surface during Laser Endodontic Therapy using 940 nm Diode Laser: An *in vitro* Study

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ABSTRACT

Objective: The objective of this study was to investigate the rise in temperature on the external root surface during 940 nm diode laser assisted root canal therapy.

Materials and methods: A total of 120 human single rooted extracted teeth were included in the study. The root canals were enlarged and laser irradiation was performed at four different settings (1 W continuous mode, 1 W gated mode 10/10, 2 W continuous mode and 2 W gated mode 10/10). The rise in temperature was measured at apical, middle and cervical thirds. The temperature changes were evaluated by a thermocouple. The threshold temperature rise of 7ºC is commonly considered as the highest temperature limit biologically acceptable to avoid periodontal damage.

Results: The mean temperature rise on external root surface in our study was below 7ºC in all parameters and all portions of root surface.

Conclusion: The 940 nm diode laser at 1 W CM, 1 W gated 10/10, 2 W CM and 2 W gated 10/10 can be considered safe for use for laser assisted root canal therapy.

Keywords: Diode laser, Endodontic treatment, Temperature rise on root surface.

INTRODUCTION

Nearly 50 years after the first dental laser was created, lasers have finally found their way onto the shelves of dental clinics. A perceived mysterious technology, whose most dramatic use is in the art of warfare, is now an integral part of the medical and dental armamentarium.

As presently used in therapeutic medical and dental applications, lasers are, in essence, devices that produce a monochromatic and directional beam of light powerful enough to do biomedical work and with much less electrical energy converted into waste heat.

In 1960, Theodore Maiman, a scientist with the Hughes Aircraft Corporation, developed the first working laser device which emitted a deep red colored beam from a ruby crystal.[7] During the next few years, dental researcher studied the possible applications of this visible laser energy.

The word Laser is an acronym for light amplification by stimulated emission of radiation.

All available dental laser devices have emission wavelength of approximately 500 to 10,600 nm. A laser consists of lasing medium contained within an optical cavity, with an external energy source to maintain a population inversion so that stimulated emission of a specific wavelength can occur, producing a monochromatic, collimated and coherent beam of light.

One of the most commonly used lasers in dentistry is diode laser. Diode laser is a solid active medium laser manufactured from semiconductor crystals similar to that found in a light-emitting diode using some combinations of aluminum or indium, gallium and arsenic. Diode lasers emit light when an electric current passes through them. Laser light is generated

Fig. 1: The 940 nm diode laser that was used for this study (Ezlase 940, Biolase®)

in a beam that is directional and monochromatic which enables laser light to be focused to a very small spot diameters needed for medical and dental applications.

The available wavelengths for dental usage for diode laser range from about 800 nm for the active medium containing aluminum to 980 nm for the active medium composed of indium, placing them at the beginning of the near-infrared portion of the invisible nonionizing spectrum.

The principle effect of laser energy is photothermal, i.e. conversion of light energy into heat energy. This thermal effect of laser energy on tissue depends on the degree of temperature rise and corresponding reaction of the interstitial and intracellular water. The rate of temperature rise plays an important role in this effect and is dependent on several factors, such as cooling of the surgical site and the surrounding tissue ability to dissipate the heat.

This rise in temperature due to thermal effect is commonly seen in laser-assisted root canal therapy. Use of diode laser as an adjunct during root canal therapy provides an additional advantage in reducing bacterial counts and thus improves the success of root canal therapy.

Successful endodontic therapy mainly depends on the elimination of microorganism from the root canal system which is traditionally accomplished by the means of biomechanical instrumentation of the root canal. Studies have shown, however, that the complete removal of microorgansims from the root canal system is virtually impossible[6,26] and a smear layer covering the instrumented walls of the root canal is formed.[18,20,21]

Peters et al (2001)[23] clearly demonstrated that more than 35% of the canals surface area remained unchanged following instrumentation of the root canal using four Ni-Ti preparation techniques.

The presence of bacteria in the dentinal tubules of infected teeth at approximately half the distance between the root canal walls and the cementodentinal junction was also reported.[2,3] These findings justify the rationale and the need for developing effective means of removing the smear layer from root canal walls following biomechanical instrumentation. This would allow disinfectants and laser irradiation to reach and destroy microorganisms harbored in the dentinal tubules.

Gutknecht et al (2004)[10] in his research using a 980 nm diode laser showed that the 980 nm diode laser can eliminate bacteria that have immigrated deep into the dentin, thus being able to increase the success rate in endodontic therapy. Benedicenti et al (2008)[4] did an *in vitro* study to investigate the bactericidal effects on root canals using an 810 nm diode laser and found that when used as an adjunct to conventional therapy, it results in increasing treatment efficiency and significantly better decontamination of the root canal.[5]

However, it also concomitantly results in a rise in the external root surface temperature which can be hazardous to the surrounding periodontal tissues and the bone if temperature rises above 10°C.[8]

The threshold temperature level of 7°C is commonly considered as the highest temperature limit biologically accepted to avoid periodontal damage.[22,25]

Studies have been done with 810 and 980 nm diode laser which show rise in temperature on external root surface of teeth following diode laser assisted root canal therapy.[1,11] Gutknecht et al 2005[11] found that there was temperature rise of not more than 7°C when irradiated up to 1.5 W and thus can be considered safe for use in laser assisted endodontic therapy.

Heysselaer et al (2007)[12] using a 980 nm laser used 3 W, 2 W and 1 W in continuous mode and found average rise in temperature at 20.7 ± 0.3°C, 9.3 ± 0.4°C and 5.8 ± 0.8°C for 3 W, 2 W and 1 W of laser irradiation on external root surface. Results showed that the use of diode laser in root canal treatments may be harmful for periodontal tissues, if the irradiation conditions are not strictly respected.

Manos and Gutknecht (2007)[19] did a study using 980 nm diode laser with the same power settings of 2.5 W at continuous mode and chopped mode and found that the temperature rising never exceeds the threshold point of thermal bone necrosis of 47°C and thus can be considered safe for periodontal tissues during laser assisted root canal treatment.

Alfredo et al 2008[1] in his study assessed the temperature variation at 1.5 W, 3 W and 5 W and found that at 1.5 W in all operating modes, and 3.0 W, in the pulsed mode, for 20s, can safely be used in endodontic treatment, irrespective of the presence of humidity. The 810 nm and 980 nm diode lasers are available in varying fiber diameters ranging from 200 to 600 µm. The end cutting property of the fiber along with a variation in diameter results in varying energy density at the tip.

Recently, a 940 nm diode laser has been manufactured for clinical use. This machine has a fiber which is constant in diameter of 400 µm but with varying tips. Thus, only the tip needs to be changed according to the usage for a particular patient. The tip most commonly used for endodontic purpose is 200 µm in diameter and 14 mm in length. No studies are available which describe the use of this wavelength for endodontics and its effectiveness in bacterial decontamination.

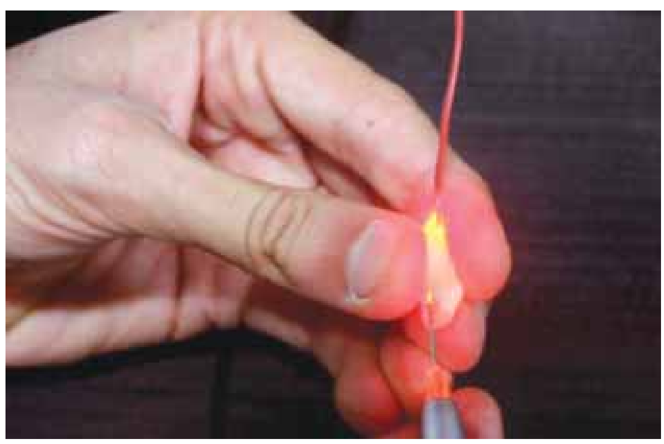

Fig. 2: Tooth being held between the fingers and thermocouple while in contact with the tooth surface to measure the temperature changes with the laser in activated mode

Fig. 3: The power meter measuring the power at the distal end of the tip

Consequently, safety parameters for 940 nm wavelength are not available.

The purpose of this study was to evaluate the thermal effect of 940 nm diode laser on external root surface, during laser assisted root canal therapy, so that this particular laser can be used at appropriate laser settings safely and effectively without any collateral damage to the periodontal tissues.

MATERIALS AND METHODS

A total of 120 human teeth having a single root and a single canal which were freshly extracted due to severe periodontal disease, and stored in normal saline immediately after extraction were used in the study. The total 120 teeth were randomly divided into four equal groups of 30 teeth each for each of the four laser parameters (n = 30). Each group of 30 teeth included 15 maxillary and 15 mandibular teeth.

Conventional access to the root canal was prepared through the crowns and access cavities were prepared using diamond burs (MANI® Dia-burs BR-41). Endodontic therapy was carried out using crown down technique. The working length was established as 1 mm short of the canal length. In each sample, a size #15 K-file could reach the apical foramen. The canals were enlarged up to an apical size of # ISO 50 with hand files (MANI®, Inc). All the canals were completely cleaned and washed with normal saline. The canals were dried with paper points.

A 940 nm gallium-aluminum-arsenide diode laser was selected for this study (Ezlase 940, Biolase®). This instrument emits laser light in the power range of 0.5 to 7 W. Pulse duration (PD) and interval duration (ID) can be changed independently in a range of 0.05 to 50 ms.

For recording of temperature changes, a thermocouple was held along the root surface either at apical third, middle third or cervical third on the proximal surface. The proximal surface of the tooth was chosen because the thickness of the root is least on the proximal surface and so more sensitive to temperature changes. The thermocouple was connected via a converter to a multimeter (PeakTech® 2010 DMM) that displayed temperature readings with a precision of 1°C. The room temperature was kept constant at 20°C.[10] During tests, the tooth was held between a thumb and index finger so that they were in contact with most of the root surface, leaving free the area where the thermocouple was attached.[24] When held with the fingers, the temperature of the tooth increased slightly above the room temperature, which was taken as the starting temperature.

The fiber of the laser (ezTip™ Endo, 14 mm/200 µm) which was 200 microns was inserted into the dry root canal and was activated at designated power settings. Laser tip was inserted till the working length and was gradually withdrawn 2 mm every second in a circular motion, according to Acchen University protocol. The time laser fiber tip was activated in the canal was thus dependant on the length of the root. The length of the root used in the study varied between 16 mm and 24 mm. Therefore, the time laser fiber was active in the root canal varied between 8 to 12 secs. The maximum temperature that occurred was recorded.

Readings were recorded at 1 W continuous mode, 1 W gated mode (10 ms pulse length, 10 ms interval duration), 2 W continuous mode and 2 W (10 ms pulse length, 10 ms interval duration) at 3 different locations on tooth surface, i.e. apical third, middle third and cervical third.

It is important to note that there was a loss of power at the distal end of the fiber tip, mainly due to the joints and loss of transmission through the fiber used. To standardize the readings for the loss of power, a power meter was used to measure the actual power emitting through the tip. 30 readings were taken at 1 W continuous mode, 1 W gated mode (10 ms interval duration, 10 ms pulse length), 2 W continuous mode and 2 W gated mode (10 ms interval duration, 10 ms pulse length). We found an average transmission loss of 20% compared to the power set on the laser unit. This was taken as the standard loss for values to be arrived at.

RESULTS

In the apical third region of the tooth surface, the mean temperature rise at 1 W continuous mode group (group I) was 4.17°C with maximum temperature recorded was 7°C and the minimum temperature recorded was 2°C. Similarly, at 1 W gated mode group (group II), the mean temperature rise was 1.80°C. The maximum rise in temperature was 3°C and the minimum rise in temperature was 1°C (Table 1).

The rise in temperature at 2 W continuous mode group (group III) was 6.47°C, the maximum rise in temperature being 11°C while 3°C being the minimum. At 2 W gated mode group (group IV), the mean rise in temperature was 2.43°C. The maximum recorded temperature was 4°C while the minimum recorded temperature was 1°C (Table 1).

Multiple comparisons for various groups in apical third show statistically significant rise in temperature between various groups (Table 2).

Table 1: Descriptive statistics for four treatments on apical third

Laser treatment	*N*	*Mean*	*Std deviation*	*Std error*	*Maximum*	*Minimum*
1W, continuous	30	4.17	1.262	0.230	7	2
1W, gated	30	1.80	0.664	0.121	3	1
	30	6.47	1.756	0.321	11	3
2W, continuous	30	2.43	0.774	0.141	4	1
2W, gated						
Total	120	3.72	2.166	0.198	11	1

Table 2: Multiple comparisons (for apical third)

Pairs compared	*Mean difference*	*Standard error*	*p-value*
1W, continuous *vs* 1W, gated	2.367*	0.260	0.0005
1W, continuous *vs* 2W, continuous	2.300*	0.395	0.0005
1W, continuous *vs* 2W, gated	1.733*	0.270	0.0005
1W, gated *vs* 2W, continuous	4.667*	0.343	0.0005
1W, gated *vs* 2W, gated	0.633*	0.186	0.007
2W, continuous *vs* 2W, gated	4.033*	0.350	0.005

*The mean difference is significant at the 0.05 level (Tamhane test)

In the middle third of the root surface, the mean temperature rise at 1 W continuous mode group (group I) was 4.23°C. The maximum temperature recorded was 7°C and the minimum temperature recorded was 2°C. Similarly, at 1 W gated mode group (group II), the mean temperature rise was 2.17°C, the maximum rise in temperature being 3°C and the minimum rise in temperature was 1°C (Table 3).

The rise in temperature at 2 W continuous mode group (group III) was 6.43°C, the maximum rise in temperature was recorded as 10°C while 3°C being the minimum. Also at 2 W gated mode group (group IV), the mean rise in temperature was 2.77°C, the maximum recorded temperature was 5°C while the minimum recorded temperature was 1°C (Table 3).

Multiple comparisons for middle third of the root show statistically significant differences between the various groups except between 1 W gated mode and 2 W gated mode which is not statistically significant (Table 4).

In the cervical third of the root surface, the mean temperature rise at 1 W continuous mode group (group I) was 3.10°C. The maximum temperature recorded was 6°C and the minimum temperature recorded was 1°C (Table 7). Similarly in 1 W gated mode group (group II), the mean temperature rise was 2.20°C the maximum rise in temperature being 3°C and the minimum rise in temperature was 1°C (Table 5).

The rise in temperature at 2 W continuous mode group (group III) was 5.03°C. The maximum rise in temperature was recorded as 8°C while 3°C being the minimum. In 2 W gated mode group (group IV), the mean rise in temperature was 2.57°C, the maximum recorded temperature was 5°C while the minimum recorded temperature was 1°C (Table 5).

Table 3: Oneway analysis for middle third

Laser treatment	*N*	*Mean*	*Std deviation*	*Std error*	*Maximum*	*Minimum*
1W, continuous	30	4.23	1.331	0.243	7	2
1W, gated	30	2.17	0.747	0.136	3	1
	30	6.43	1.775	0.324	10	3
2W, continuous	30	2.77	0.971	0.177	5	1
2W, gated						
Total	120	3.90	2.072	0.1889	10	1

Table 4: Multiple comparisons (for middle third)

Pairs compared	*Mean difference*	*Standard error*	*p-value*
1W, continuous *vs* 1W, gated	2.067*	0.279	0.0005
1W, continuous *vs* 2W, continuous	2.200*	0.405	0.0005
1W, continuous *vs* 2W, gated	1.467*	0.301	0.0005
1W, gated *vs* 2W, continuous	4.267*	0.352	0.0005
1W, gated *vs* 2W, gated	0.600	0.224	0.007
2W, continuous *vs* 2W, gated	3.667*	0.369	0.005

*The mean difference is significant at the 0.05 level (Tamhane test)

Multiple comparisons for the cervical thirds of the root show statistically significant differences between the various groups except between 1 W continuous mode and 2 W gated mode and also between 1W gated mode and 2 W gated mode which is not statistically significant (Table 6).

DISCUSSION

The root canal disinfection process begins with biomechanical preparation which includes mechanical action of instruments and chemical action of irrigant solutions. However, these procedures do not completely eliminate the microorganisms present in long-standing infectious processes[17] or in canals that have flattened areas and accentuated curves which is difficult to access by instruments.[4] The complex anatomy of root canal system may offer opportunity and conditions for the growth and multiplication of microorganisms.[4,9]

Currently, lasers are being used widely in endodontics because it presents the capacity for microbial reduction in the root canals at depths of up to 1 mm in the dentinal canaliculi, a higher distance than that achieved by chemical substances, thus justifying its use in the field of endodontics.[13,14]

This study was undertaken to establish safe levels of laser energy administration into the root canals. There are some guidelines published by the companies that manufacture commercially available lasers, but these guidelines are given more as settings for each machine than as energy delivery per time unit. Moreover, there is some loss of energy toward the distal end of the tip. Gutknecht et al 2005[10] found that the power emitted at the distal end of tip was reduced to only 20 to 30% of the value indicated on the laser controls, mainly due to the joining parts and very thin fiber that was used. However, in our study, we found that the power was reduced to 70-80% of the value indicated on the laser controls. This was confirmed throughout the study by using a power meter intermittently. It is very important to know what power is emitted at the distal end of the fiber compared to the value indicated on the laser control so as to standardize the power on laser controls for various treatment modalities.

The temperature measurements of our study were performed at room temperature 20°C which is in accordance to Gutknecht et al 2005.[10]

In the present study, the tooth was held with the thumb and index finger so that they were in contact with most of the root surface, leaving free the area where the thermocouple was attached. This situation was used to simulate the *in vivo* situation, with the removal of energy by the blood circulation in the finger tissues mimicking the cooling effect of blood circulation in the periodontal ligament and adjacent jawbone. This is similar to the protocol followed by Ramskold et al 1997.[24] The thermal bath was not used because contact of the thermocouple and the laser tip with water during irradiation in root canal would hinder the execution of the experiment, since the temperatures were measured on the cervical, middle and apical third using thermocouples in contact with the root surface simultaneous to the movements of the laser tip in the interior of root canals. Also, Ramskold et al 1997[24] consider that the thermal bath is less similar to the in vivo situation, due to the freely circulating water and to the large volume of cooling liquid available in the water bath.

In the present study, proximal surfaces of the teeth were selected for measuring temperature as proximal surfaces of teeth contain the least thickness of dentin and hence are susceptible to greater rise in temperatures following laser use. One of the concerns about laser application inside the root canals is the conversion of light energy into caloric energy during the interaction with dentinal structures, which could cause a temperature rise on the external surface of the root and adjacent structures. This rise in temperature on external root surface can cause damage to the cementum layer, predisposing to resorption of roots, damage to periodontal ligament and alveolar bone necrosis. The severity of the effects is determined by the quantity of heat generated and the time it persists in the

Table 5: Oneway analysis for cervical third

Laser treatment	*N*	*Mean*	*Std deviation*	*Std error*	*Maximum*	*Minimum*
1W, continuous	30	3.10	1.185	0.216	6	1
1W, gated	30	2.20	0.887	0.162	3	1
	30	5.03	1.497	0.273	8	3
2W, continuous	30	2.57	0.898	0.164	5	1
2W, gated						
Total	120	3.23	1.574	0.144	8	1

Table 6: Multiple comparisons (for cervical third)

Pairs compared	*Mean difference*	*Standard error*	*p-value*
1W, continuous *vs* 1W, gated	0.900*	0.270	0.009
1W, continuous *vs* 2W, continuous	1.933*	0.349	0.0005
1W, continuous *vs* 2W, gated	0.533	0.271	0.286
1W, gated *vs* 2W, continuous	2.833*	0.318	0.0005
1W, gated *vs* 2W, gated	0.367	0.230	0.526
2W, continuous *vs* 2W, gated	2.467*	0.319	0.005

* The mean difference is significant at the 0.05 level (Tamhane test)

region.[8,15,25] According to Eriksson and Albrektsson 1983,[8] the temperature of 47°C (10°C above body temperature) for 1 min is sufficient to cause necrosis of the alveolar bone. In the present study, the use of 940 nm diode laser during root canal therapy at 1 W continuous mode, 1 W gated mode (10 ms interval duration10 ms pulse length), 2 W continuous mode and 2 W gated mode (10 ms interval duration 10 ms pulse length) did not result in temperature rises more than 10°C. In our study, the mean maximum rise in temperature was seen in 2 W continuous mode group which was 6.47°C. This is much below the temperature rise threshold suggested by Eriksson and Albrektsson 1983.[8] The maximum rise in temperature of 11°C was seen in one of the teeth in 2 W continuous mode group. This high value in this particular tooth was due to thin root surface of lower central incisor as well as a root concavity present on proximal surface which would together result in thin dentinal thickness.

The mean rise in temperature on the outer root surface after laser assisted root canal therapy in our study at 1 W continuous mode group was 4.17°C in the apical third region. Gutknecht et al 2005[10] found a rise of 5.2°C at 0.6 to 1 W in continuous mode group in apical third region at the end of 10 secs cycle. Similarly, the mean rise in temperature in the apical third region in our study, after 1 W gated mode at 10 ms interval duration 10 ms pulse length (10/10) was 1.80°C. In contrast, Gutknecht et al 2005[10] found a rise of 4°C after using laser at 0.6 to 1 W 10/10 group at the end of 10 secs cycle.

The mean temperature rise after application of 940 nm diode laser during root canal therapy at 2 W continuous mode group in our study was 6.47°C. Alfredo et al 2008[1] found a mean rise in temperature of 6.06°C at laser parameters of 1.5 W continuous mode. Gutknecht et al 2005[10] in his study at 1 to 1.5 W continuous mode found that the mean rise in temperature was 8°C at the end of 10 secs cycle.

Similarly in gated mode group at 2 W (10/10), we found a mean temperature rise of 2.43°C while Gutknecht et al 2005[10] found a mean rise of 3.4°C in 1 to 1.5 W gated mode group after 10 secs cycle. Similarly, Alfredo et al 2008[1] found 2.85°C mean rise in temperature at 1.5 W gated mode at 100 Hz. Thus results in our study are in agreement to those of Gutknecht et al 2005[10] and Alfredo et al 2008[1] in which they concluded that application of continuous mode resulted in higher temperature rise on the root surface in comparison with gated mode.

Another important factor in heat conduction between the canal and the periradicular tissues is the thickness of the dentinal walls. In our study, we found that the maximum rise in temperature was found in the apical third region (6.47°C), followed by middle-third (6.43°C) and lastly in cervical third region (5.03°C). Thus, thinner root dentin thickness more was the rise in temperature. Thicker walls more difficult for passage of heat through it. However, Alfredo et al 2008[1] in contrast found highest temperature rise in the cervical third (9.65°C), followed by the middle-third (7.67°C) and lastly the apical third (6.73°C). This was attributed to the back and forth movement of the laser along the canal during lasing and also because roots without crowns were used, which enabled greater inclination of the laser fiber in the cervical region, directing the light beam more perpendicularly to the dentinal wall, and thus achieving greater efficiency in energy delivery than in the other thirds. Also, back and forth movements might have resulted in irradiation staying longer and continuously in the cervical third, causing higher temperature rises.

This study was done *in vitro*. We understand that *in vitro* conditions will be different from *in vivo* conditions. However, we have tried to mimic the *in vivo* temperature rise as closely as possible.

It is important to remember that the powers used in this study are special for this instrument and wavelength only. It is incumbent upon every clinician to get his laser machine calibrated from the manufacturer so as to get most accurate results. Every clinician should measure the output energy of the diode laser with a power meter and use it only with power outputs that are considered safe. In our study, all the parameters were found to be within safe range.

Also one has to be careful and thorough with the anatomy of the teeth as thickness of dentin is different in different teeth and so more rise in temperature can be anticipated in teeth with thin dentin, like lower incisors, as was found in our study where we had a 11°C rise in temperature in a lower incisor. So the laser parameters may have to be adjusted accordingly to prevent damage to the periodontium. However, it is very important to know whether the laser parameters which do not result in significant rise temperature are also effective for bacterial decontamination. Not many studies have been done which compare the effectiveness of the diode laser on bacterial decontamination with rise of temperature on the external root surface. Kreisler et al 2003[16] did a study with 809 nm diode laser at 1.5, 3.0 and 4.5 W at continuous mode and found that there was bacterial decontamination without excessive heat generation on the outer root surface.

Further research needs to done to observe the effectiveness of 940 nm diode laser on bacterial decontamination and rise of temperature on external root surface to optimize its effects.

CONCLUSION

The results of this study showed that 940 nm diode laser at 1 W CM, 1 W gated 10/10, 2W CM and 2 W gated 10/10 can be considered safe for use for laser assisted root canal therapy when used in a circular motion and withdrawn at 2 mm every second. The temperature rise was maximum in the apical third region followed by middle third region and least in the cervical third region following laser use. Calibration of the laser is essential to know how much power is emitted at the distal end of the tip so as to standardize the power on laser controls for various treatment modalities.

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