Thermal effects associated with the Nd/YAG dental laser

J.A. von Fraunhofer, MSc, PhD; and D.J. Allen, DDS, MS

The reported applications of lasers to a variety of dental procedures are growing and have prompted a great deal of interest, particularly for soft tissue surgery, etching of dental enamel and to facilitate debonding of orthodontic brackets. Although the clinical effects obtained with lasers may be ascribed to thermal effects at the workpiece surface, the literature on heat generation at the target or workpiece surface and its effects on the hard and soft tissues is, at best, confusing. Further, there is little information to date on thermal effects to the pulp caused by laser irradiation.

There have been various reports regarding thermal effects on the dental pulp[1-4] and, more recently, the pulpal heating effects associated with the use of the dental laser.[5-10] These studies indicate, overall, that a temperature rise of 10°F (approx. 6°C) can cause irreversible pulpal responses and temperatures in excess of 20°F (approx. 11°C) may cause necrosis of the pulp[2]. Temperatures of this magnitude are known to occur during cavity preparation with uncooled burs and may occur during polishing and finishing of restorations.[2,4]

Lesions of the pulp tissue caused by thermal effects from cutting procedures usually are confined to that portion of the pulp underlying the inner ends of cut dentinal tubules. Frictional heat, if not excessive, can increase the intensity of the

Abstract

The heat produced at the dentinal pulpal wall opposite the irradiation site was measured during etching of dental enamel with an Nd:YAG laser in preparation for direct bonding of orthodontic appliances.

Forty extracted human teeth were randomly divided into four groups of 10 teeth. Within each group, the buccal surfaces of 5 teeth and the lingual surfaces of the other 5 teeth were laser treated for 12 sec. Irradiation was performed with a commercial Nd:YAG laser at the power settings of 80mJ, 1W, 2W and 3W. Prior to irradiation, an occlusal access preparation was made into the pulp in order to facilitate the placement of a thermocouple for measurement of temperature changes at the dentinal pulpal wall opposite the irradiation site. The thermocouple was held against the dentinal pulpal wall and the resulting temperature changes were recorded.

Heating effects at the dentinal pulpal wall on both buccal and lingual surfaces showed an increase in heat as a function of the increase in power output from the laser unit ($p<0.01$). The temperatures measured at power levels 1-3W appeared to be of sufficient magnitude to cause at least localized pulpal inflammation and possible irreversible damage to the pulp tissue immediately opposite the site of laser irradiation.

Keywords

Lasers • Etching • Thermal effects

Submitted: May 1992 **Revised and accepted for publication:** March 1993 Angle Orthod 63:299-304

Table 1
Laser irradiation regimens: power outputs for 12 sec irradiation

Power Setting	Level	Pulse rate (Hz)	Output (J)	Calories
80mJ	-	10	9.6	2.29
1 Watt	2	20	12.0	2.87
2 Watts	6	20	24.0	5.73
3 Watts	10	20	36.0	8.60

Table 2
Mean dentin and enamel thicknesses and mean maximum temperature rises for different irradiation regimens

Tooth Group and irradiation regimen	Mean dentin thickness (mm)	Mean enamel thickness (mm)	Total tooth thickness (mm)	Maximum temp. rise (°C)
1-5 Buccal 2W/12s/20Hz	1.86	1.34	3.20 ±0.51*	9.80±2.17
6-10 Lingual 2W/12s/20Hz	0.74	1.10	1.84 ±0.47	16.50±2.08
11-15 Buccal 1W/12s/20Hz	1.44	1.12	2.56 ±0.55	7.80±1.48
16-20 Lingual 1W/12s/20Hz	0.74	0.82	1.56 ±0.49	13.25±3.30
21-25 Buccal 3W/12s/20Hz	1.58	1.12	2.70 ±0.39	20.60±1.67
26-30 Lingual 3W/12s/20Hz	0.84	1.06	1.90 ±0.34	38.75±4.65
31-35 Buccal .8W/12s/10Hz	1.44	1.52	2.96 ±0.33	5.40±1.34
36-40 Lingual .8W/12s/10Hz	1.50	1.34	2.84 ±0.27	4.40±0.89

*mean ± standard deviation.

pulp response without expanding the lesions beyond this region. However, if the insult to the pulp is great enough, burn lesions can present as coagulation necrosis and often develop intrapulpal abscesses. Abscess formation appears to occur quite early and may remain indefinitely.[11] Resolution of a large burn area can occur with the entire area involved first filling in with granulation tissue. This tissue then undergoes reorganization by stimulated odontoblasts with resultant reparative dentin formation. However, if healing is not successful, a large expanding abscess will develop.

Occasionally, in a pulp that is healthy peroperatively, certain abscess-like conditions (dense accumulations of leukocytes between the odontoblastic layer and the predentin) will occur beneath the cavity preparations. Although these conditions will resolve, any technique that produces either abscess or abscess-like conditions should be modified or eliminated. These characteristics are not necessarily localized but sometimes they can be quite focal.[11]

The literature on laser heating effects on the pulp[5,7,8,10,12-15] is somewhat conflicting. Some authors have reported no pulpal damage with laser irradiation while others observed various degrees of damage, depending upon the laser used and the power setting of the laser. McCarthy[14] used an Analytic Technology vitalometer to measure pulp vitality before and immediately following Nd:YAG irradiation and although he acknowledged there was much room for error when taking the readings, he reported that preliminary results suggested there is little or no change in the vitality of the irradiated teeth. White[5], studying the effect of the Nd:YAG laser operating at $\leq$240J on third molars within 3 minutes of extraction, reported no significant *in vitro* pulpal disruption when the remaining dentin thickness was greater than 1mm.

In contrast, Melcer,[13] using a CO_2 laser at 5×10^3 J/cm^2, reported pulpal responses consistent with thermal insult and calcified repair in the pulp chamber that reduced the pulpal volume by approximately one third. Shoji and Horiuchi[12] irradiated rat teeth with an acousto-optically Q-switched Nd:YAG laser at 10W for 0.2 seconds or 5W for 0.3 seconds using a beam diameter of 2 mm and found that the pulp showed mild dilatation of vessels at the lowest levels with some calcified tissue 4 weeks after laser irradiation. The pulpal response of reparative dentin formation increased with higher power levels. Adrian et al,[7] working with a ruby laser, reported minimal pulp damage between 1880 and 2330 J/cm^2 but coagulation necrosis of the odontoblasts, edema and occasional inflammation occurred between 2400 and 3300 J/cm^2. Similar thermal effects of laser irradiation have been reported by others.[7,10,14,15] In virtually every case, the effects reported paralleled those observed in polishing studies[2,4] with pulpal damage occurring when the temperature elevation exceeded 10°F while effects arising from temperature changes of less than 10° appear to be reversible.

Given the interest in orthodontic applications of dental lasers, particularly enamel etching and bracket/attachment debonding, the present study was undertaken to investigate the heating effects within the pulp chamber arising from laser etching of the enamel surface.

Materials and methods

This study used 40 freshly extracted, non-carious human maxillary and mandibular premolars and third molar teeth which were stored continuously in distilled water at 10°C, with the water changed weekly to minimize bacterial growth. The teeth were randomly assigned into four groups of 10 teeth with approximately equal numbers of each tooth type in the four groups. The tooth roots were embedded in dental stone encased in plastic cylinders and the teeth provided with occlusal access preparations that exposed the total pulp chamber and pulpal dentinal wall. All pulpal tissue was removed and the pulpal walls were cleaned free of debris. The external surfaces of the teeth were then polished for 5 seconds with a rubber prophy cup using a pumice/water slurry containing no oils or fluoride, then rinsed and air dried.

All laser irradiation work was performed with a Nd/YAG laser (dLase 300, American Dental Laser, Troy, MI). Before laser etching of the enamel surface, a Type T copper-constantan thermocouple (Omega Engineering, Stamford, CT) with reference junction at 0°C was placed in the pulpal cavity against the dentinal wall of the enamel surface to be irradiated. The temperature was recorded automatically by an Omega Engineering three pen high impedance chart recorder during laser irradiation. Due to poor surface absorption of the Nd:YAG laser beam, dental enamel must be coated with an "initiator" such as a carbon suspension or black ink and in this study, a thin layer of black paint (Catman Water Colors, ivory black 331) was applied to the enamel with a nylon brush covering an area of approximately 16

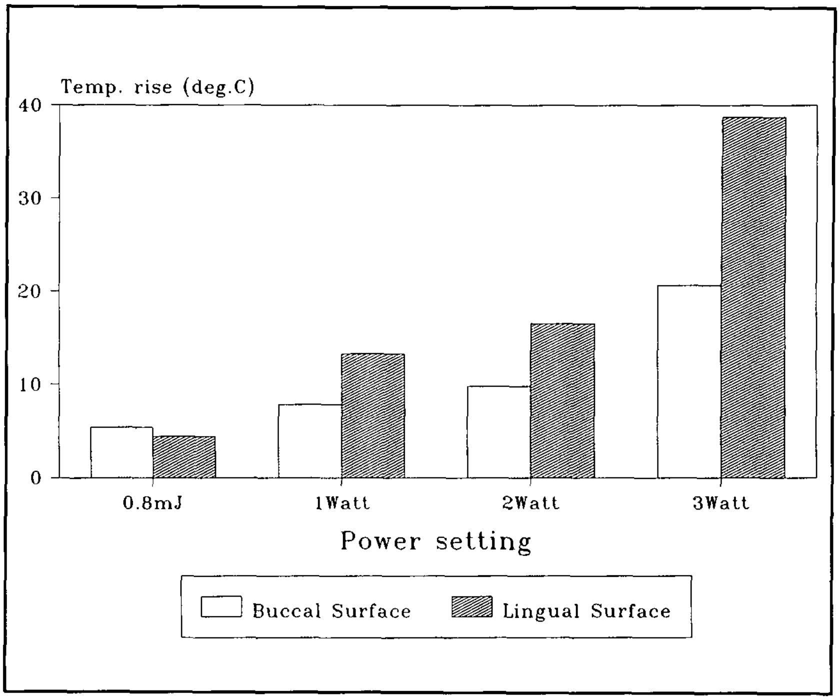

Figure 1

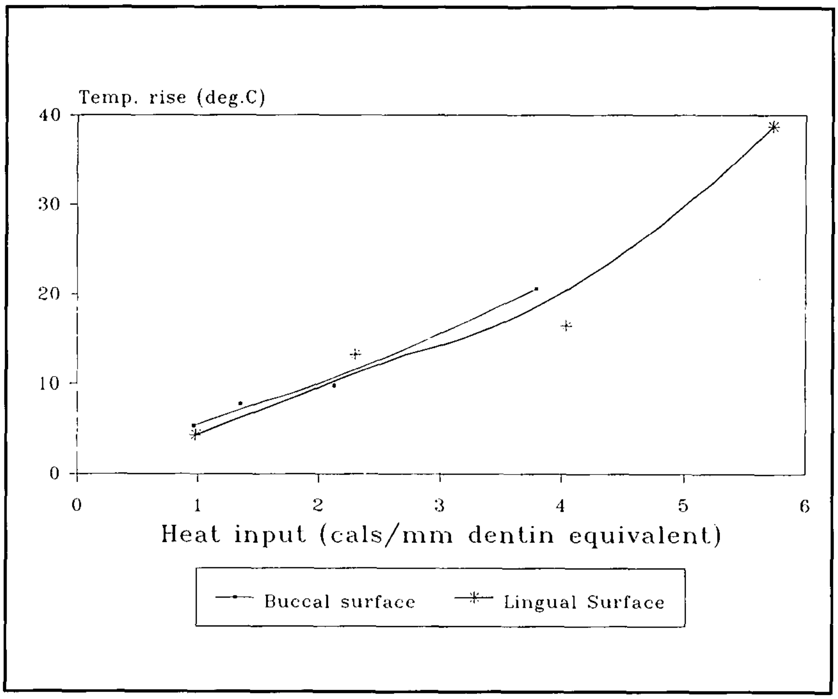

Figure 2

Figure 1
Temperature rise (°C) for buccal and lingual surfaces for laser power settings of 0.8mJ, 1, 2 and 3 watts.

Figure 2
Temperature rise (°C) for buccal and lingual surfaces as function of the heat input (calories/ mm dentin equivalent).

Table 3
Test regimens, heat inputs and temperature rises for buccal surfaces with dentin and enamel thicknesses expressed as dentin equivalents. (Heat diffusivity cm²/s: 1mm enamel = 0.62mm dentin)

Regimen	Calorie Input	Temperature rise (°C)	Mean enamel thickness (mm)	Mean dentin thickness (mm)	Mean total thickness (mm)	Equivalent dentin thickness (mm)
0.8W	2.29	5.40	1.52	1.44	2.96	2.38
1.0W	2.87	7.80	1.12	1.44	2.56	2.13
2.0W	5.73	9.80	1.34	1.86	3.20	2.69
3.0W	8.60	20.60	1.12	1.58	2.70	2.27

Table 4
Test regimens, heat inputs and temperature rises for lingual surfaces with dentin and enamel thicknesses expressed as dentin equivalents. (Heat diffusivity cm²/s: 1mm enamel = 0.62mm dentin)

Regimen	Calorie input	Temperature rise (°C)	Mean enamel thickness (mm)	Mean dentin thickness (mm)	Mean total thickness (mm)	Equivalent dentin thickness (mm)
0.8W	2.29	4.4	1.34	1.50	2.84	2.33
1.0W	2.87	13.25	0.82	0.74	1.56	1.25
2.0W	5.73	16.50	1.10	0.74	1.84	1.42
3.0W	8.60	38.75	1.06	0.84	1.90	1.50

mm². This area approximates the base area of a standard stainless steel premolar orthodontic bracket used in direct bonding. The selected enamel surface was then etched at the preselected power levels of 80mJ, 1 W, 2 W and 3 W for 12 sec (see Table 1). The etching regimen involved passing the fiber optic cable tip across the painted area in a horizontal fashion starting from the occlusal aspect and working toward the gingival aspect having the optic fiber in contact with the tooth surface. The initiator was removed by the laser beam within the 12 second laser etch time period in all specimens.

After laser irradiation to remove the initiator, the temperature continued to rise for a few seconds after the laser beam was switched off. This indicated that the thermocouple itself was not directly affected by laser irradiation, rather measuring the heat transmitted through tooth substance. Accordingly, the maximum temperature rise was recorded and the temperature elevations for the four etching regimens and 10 teeth in each etch group were subjected to a one way ANOVA to determine whether differences existed in the thermal effects and individual differences were identified with a post hoc Tukey-Kramer hsd test at an *a priori* $\alpha=0.05$.

It should noted that there is some confusion in the literature over thermal effects associated with lasers, primarily because authors often use different units to describe their laser treatment regimens. Accordingly, a standardized notation, given in the appendix, will be used

Results

The maximum temperature rises observed for the different irradiation regimens for buccal and lingual surfaces are given in Table 2 and Figure 1. Table 2 also contains the mean thicknesses of enamel, dentin and the total enamel+dentin thickness for each group of teeth.

Temperature elevation increased with laser power output, Figure 1, with the rise exceeding the temperature for possible irreversible pulpal damage (6°C[2,10]) at power outputs of 1-3W. Examination of the data in this histogram suggests that there are differences in the thermal responses of the buccal and lingual tooth surfaces. Statistical analysis indicated that there were differences ($p<0.01$) in the observed maximum temperature rises and the total tooth thicknesses for all tests groups except for the teeth subjected to irradiation at 0.8W ($p>0.05$). However, when the total tooth (enamel and dentin) thicknesses are converted to dentin equivalents, as in Tables 3 and 4, and these values are used to calculate heat input in terms of dentin equivalents, the temperature rise for the buccal and lingual surfaces are the same ($p>0.05$) for each irradiation regimen (Figure 2).

Discussion

Reports on thermal effects arising from laser irradiation in the literature tend to be conflicting[1-10] although there is a general consensus that pulpal temperature elevations in excess of 6°C may result in irreversible damage.[2,10] The findings of this study indicate that temperature elevations at the dentinal pulpal wall during laser irradiation with the laser used in the present study exceed 6°C at power outputs of 1-3W. The study indicated that the observed temperature rise, for a given irradiation regimen, is determined by the tooth thickness with lower temperature rises associated with a greater dentin thickness.

A previous study[17] has shown that consistent direct bonding of orthodontic attachments required the dental enamel to be irradiated at an output power ≥2W with a commercial Nd:YAG laser. The findings of this study suggest that laser irradiation for the modification of the dental enamel preparatory to direct bonding may pose a distinct thermal risk to the pulp and caution should be exercised in laser "etching" of enamel.

Author Address

Dr. J. A. von Fraunhofer
School of Dentistry
Health Sciences Center
University of Louisville
Louisville, KY 40292

Dr. von Fraunhofer is professor and director of the Laboratory of Molecular and Materials Science, School of Dentistry, University of Louisville.

Dr. Allen obtained his specialty training and his MS degree at the University of Louisville and is now in private orthodontic practice in Wheaton, Illinois.

References

1. Nyborg H, Brannstrom M. Pulp reaction to heat. J Prosthet Dent 1968;19:605-612.
2. Zach L, Cohen G. Pulp response to externally applied heat. Oral Surg Oral Med Oral Path. 1965;19:515-530.
3. Schuchard A, Watkins C. Temperature response to increased rotational speeds. J Dent Res 1960;39:738.
4. Peyton F. Temperature rise in teeth developed by rotating instruments. J Amer Dent Assoc 1955;50:629-632.
5. White J, Goodis H, Rose C, Daniels T. Study of effects of Nd:YAG laser on pulps of extracted human teeth. Unpublished. 1990.
6. Seltzer S. Bender IB. The Dental Pulp - Biologic Considerations in Dental Procedures. JB Lippincott Co. (Second Edition) 1975 pp 183-193.
7. Adrian C, Bernier J, Sprague W. Laser and the dental pulp. J Amer Dent Assoc 1971;83:113-117.
8. Stern R, Renger H, Howell F. Laser effects on vital dental pulps. Brit Dent J 1969;152:26-28
9. Taylor R, Shklar G, Roeber F. The effects of laser radiation on teeth, dental pulp, and oral mucosa of experimental animals. Oral Surg Oral Med Oral Path 1965;19:786-795
10. Powell G, Whisenant B, Morton T. Carbon dioxide laser oral safety parameters for teeth. Lasers in Surgery and Medicine 1990;10:389-392.
11. Stanley HR. Human pulp response to operative dental procedures. Storter Printing Co.Inc. 1976; pp.60-61.
12. Shoji S, Horiuchi H. Histopathological changes of dental pulp after irradiation by Argon, Carbon - Dioxide or Nd:YAG laser in rats. Lasers in Dentistry. Elsevier Science Publishers BV, Amsterdam, 1989, pp.253-258.
13. Melcer J. More than ten years of CO_2 laser research and clinical applications in dentistry: clinical results. Lasers in Dentistry. Elsevier Science Publishers BV, Amsterdam, 1989, pp.41-46.
14. McCarthy D. Vitality of lased teeth. Abstract. Supplement (ISSN 0243-7228). 1990
15. Lanaunay Y, Mordon S, Cornil A, Brunetaud J, Moschetto Y. Thermal effects of lasers on dental tissues. Laser in Surgery and Medicine 7:473-477 1987
16. Braden M. Heat conduction in normal human teeth. Arch Oral Biol 1964;9:479-486.
17. von Fraunhofer J A, Allen D J, Orbell G M: Laser etching of enamel for direct bonding. Angle Orthod 1993;63:73-76.

Appendix

The American Dental Nd/YAG laser delivers 0.3 to 3 watts at pulse rates of 10 to 30 Hz, the laser beam typically being transmitted through a contact fiber-optic cable 320 μm in diameter and with a cross-sectional area 0.08 mm^2. It should be noted that energy is expressed in Joules (J) while power is expressed in Watts (W), where 1W = 1J/s. The energy emitted at the fiber-optic cable tip is the power density, i.e. the power per pulse per unit fiber-optic cable cross-sectional area. Thus, for a laser operating at 2W and 20Hz using a 320μm dia. fiber-optic cable, the power density is 124.4 J/cm^2 at the fiber-optic cable tip. However, the energy emitted at the cable tip is given by the product of the power density and the time of laser emission. Thus, a laser operating at 2W and 20Hz for 12 seconds emits 1492.6 Joules (i.e. approx. 1500J) and since energy input of 4.19J to a surface is 1 cal, there is an energy input of approx. 356 cal from a laser operating at 2W and 20Hz for 12 sec at 100% energy-transfer efficiency.