

Table 2.7.a. Rating scale for cell disruption on decalcified sectioning with H&E staining

- 0- Normal cellular elements in the pulp area underlying the zone of laser irradiation.
- 1- Disruption of the odontoblastic cell layer underlying the zone of laser irradiation, including: elongation, irregular cytoplasmic membranes, vacuolisation and subodontoblastic oedema.
- 2- Disruption of the odontoblastic cell layer underlying the zone of laser irradiation, including: loss of stroma and viable epithelial root sheath of the odontoblastic layer, cytoplasmic changes, and aspirated odontoblasts.

Specimen no.	RDT	1-Ratings	2-Ratings	Ave. Ratings
58961(L)*	2.0	0	0	0
58961(C)*	2.0	0	0	0
58962(L)	2.0	0	0	0
58962(C)	2.1	0	0	0
59961(L)	1.9	0	0	0
59961(C)	2.0	0	0	0
59962(L)	2.0	0	0	0
59962(C)	2.0	0	0	0
61961(L)	1.9	0	0	0
61961(C)	1.9	0	0	0
61962(L)	2.0	0	0	0
61962(C)	2.0	0	0	0

RDT= Remaining dentine thickness (mean thickness of 2.0± 0.04mm)
(C)= Control group, (L)= Laser group.
(*)= Shows mild elongation and subodontoblastic spacing.



Fig.2.7.a. LM(100x) of the external pulp underlying the cervical half of the palatal surface, from a typical control specimen.



Fig.2.7.b. LM(100x) of the pulp underlying the zone of irradiation, at the cervical half of the palatal surface, from a typical Laser-treated specimen demonstrates normal pulpal histology.

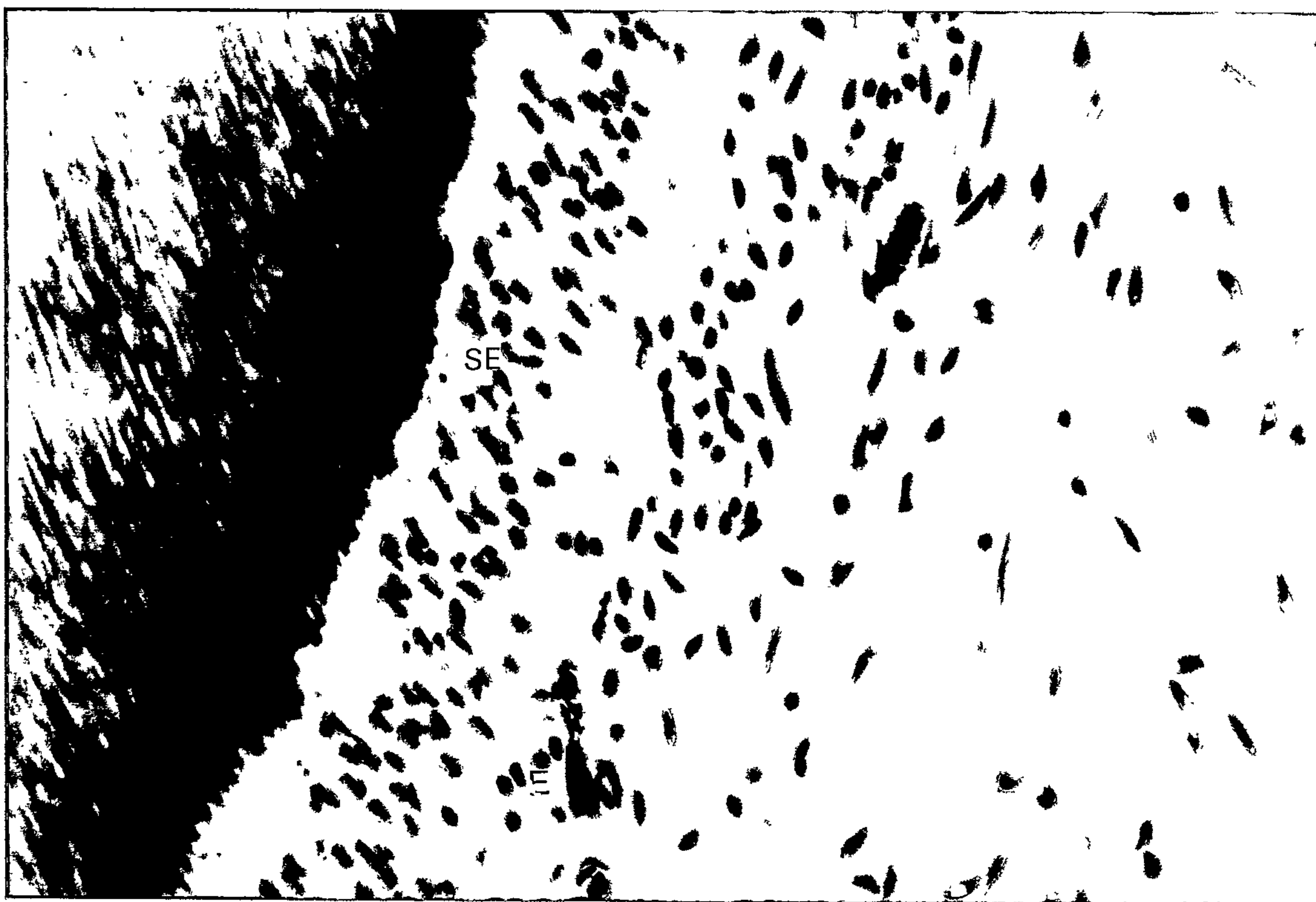


Fig.2.7.c. LM(100x) of the pulp underlying the zone of irradiation, from a typical Laser-treated specimen- mild elongation (E) and subodontoblastic oedema (SE) of the odontoblastic cell layer.

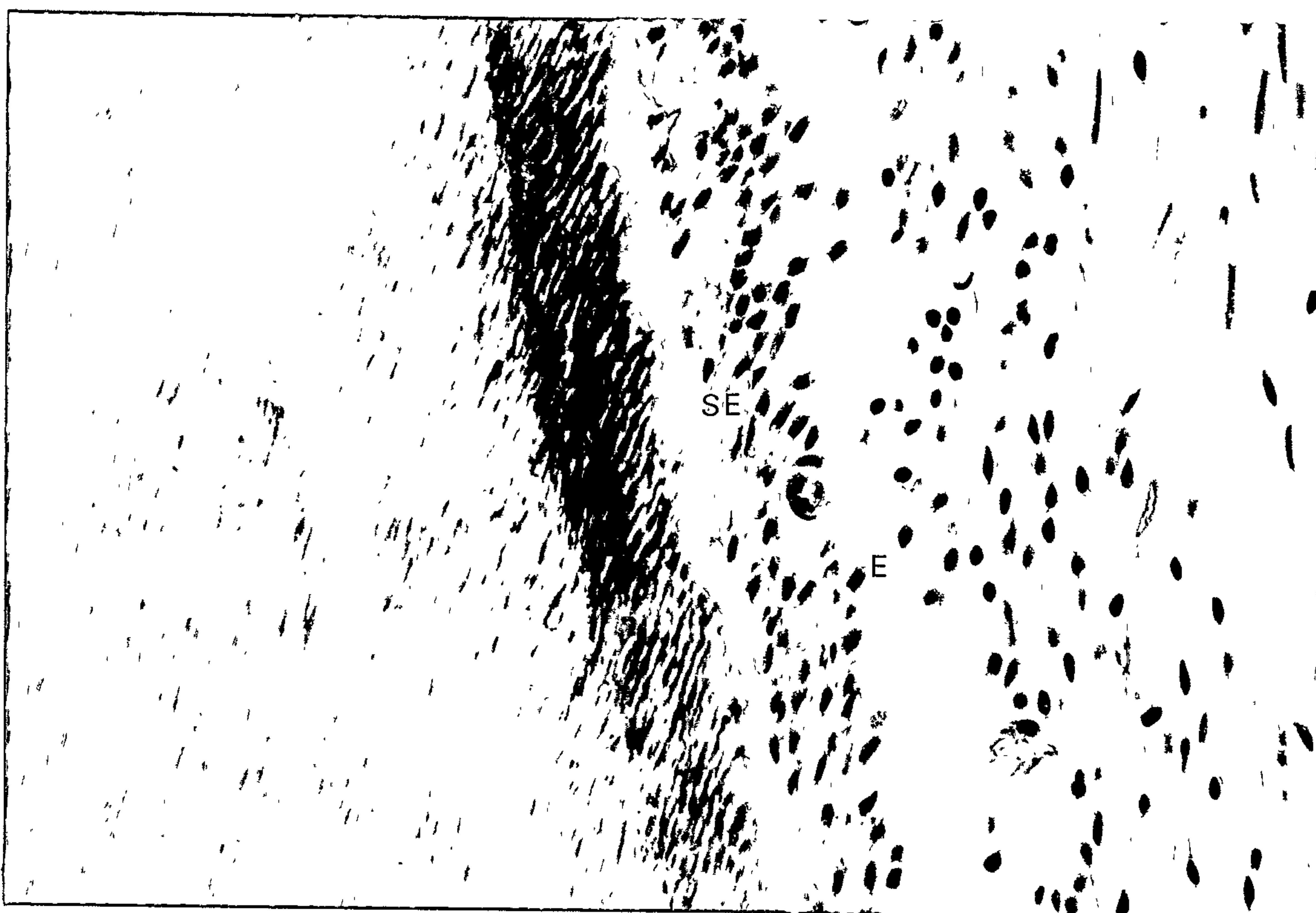


Fig.2.7.d. LM(100x) of the pulp underlying the cervical half of the palatal surface, from a typical control specimen- mild elongation (E) and subodontoblastic oedema (SE) of the odontoblastic cell layer.

2.8. Conclusion

In conclusion these series of pilot studies have shown that exposure of cervical half of the tooth surface (buccal and lingual/palatal) to Nd:YAG laser pulses for clinical inducing pulpal anaesthesia, with the energy density range of 73-107J/cm² (320 micron fibre), and total energy dose in the range of 106-156J/surface (120sec/surface), followed by highspeed bur cavity cutting is safe and it caused:

- i) no enamel surface alterations when observed under Scanning Electron Microscopy.
- ii) no atypical enamel and dentine layer alterations when observed under longitudinal undecalcified ground-sectioning.
- iii) little reduction in dentinal permeability in 3/10 (30%) cases, using 5% methylene blue dye penetration method (observed the penetration of the dye, from the pulp towards the dentino-enamel junction).
- iv) induced mild superficial pulpal disruptions which included the elongation, irregular cytoplasmic membranes, vacuolisation and subodontoblastic oedema, of the odontoblastic cell layer. Such changes were comparable with that of EMLA (with highspeed cavity cutting), with the mean remaining dentine thickness of 1.84 ± 0.18 mm. A further pilot study to define the histological variation between the control and the

Laser treated teeth has shown no immediate (30min) atypical superficial pulpal changes after laser clinical induction to pulpal anaesthesia.

3. The rise in intrapulpal temperatures under prolonged irradiation of pulsed Nd:YAG laser on teeth. An *in vitro* study.

3.1. Introduction and aims

In recent years, the pulsed Nd:YAG laser, particularly the American Dental Laser, has been used in clinical dentistry for various hard and soft tissue procedures (Hardee *et al.*, 1990; Myers and Myers, 1985a; White *et al.*, 1991c; Yamamoto and Sato, 1980; White *et al.*, 1991e). Laser induced surgical anaesthesia is one of the useful applications in dentistry in managing apprehensive and paediatric patients. The clinical efficacy of this form of anaesthesia had been confirmed by a number of authors (Parkins and Miller, 1992; Matsumoto, 1994; Chan and Punnia-Moorthy, 1994; Orchardson and Whitters, 1996), using various techniques and energy parameters. It has been shown (Orchardson and Whitters, 1996) in an animal study, the level of anaesthesia on dentine could be increased with an increase in laser energy dosage, but the doses required to achieve this may cause damage to the nerve (Orchardson *et al.*, 1994) and the pulp (Suda *et al.*, 1996).

Nd:YAG laser radiation is in the near infrared region of the electromagnetic spectrum, with a wavelength of 1064nm. Laser energy of this wavelength is absorbed strongly in black-pigmented tissues and

readily transmitted through dental enamel and dentine (White *et al.*, 1991). Consequently, thermal energy transmitted into the pulp, during laser irradiation on dental hard tissues, will bring about a rise in pulpal temperature.

Studies (Zach and Cohen, 1962; Stern *et al.*, 1969; Adrian *et al.*, 1971; Zach, 1973; Serebro *et al.*, 1987; Melcer *et al.*, 1987; Renneboog-Squilbin *et al.*, 1989; Arcoria *et al.*, 1991) have demonstrated that normal odontoblastic cellular structure and function cannot survive in elevated intrapulpal temperature for long time periods when irradiated with visible and infrared lasers.

In theory, the pulsing ability of the laser source allows cooling between pulses, thus can reduce the detrimental thermal effect of the continuous laser wave (Leighty *et al.*, 1991; Khosrovi *et al.*, 1991). Nevertheless, it is critical to investigate the potential risk for thermal injury to the dental pulp especially in dental application such as laser induced surgical anaesthesia which requires a prolonged time of laser exposure.

Thresholds for adverse pulp response to temperature increase have been defined by Zach and Cohen (1965) as; 1) below 2.2°C - no histological changes occur; 2) below 5.5 °C - inflammation is mild and reversible; 3) above 5.5 °C - 15% of teeth have a loss of vitality and pulp necrosis occurs.

The aims of this *in vitro* study were to investigate the profile of temperature changes under a prolonged irradiation of pulsed Nd:YAG laser energy, simulating the exposure which might occur in clinical laser induced pulpal anaesthesia, and to determine the laser safety exposure parameters, in relation to the thermal safety limits as defined by Zach and Cohen.

3.2. Materials and methods

Recently extracted human, caries-free premolar teeth that were removed for orthodontic reasons were collected and stored in an aqueous 0.2% thymol solution to inhibit bacterial growth until used. The roots and the pulp content of these teeth were removed and K-type thermocouples inserted against the internal dentinal surface of the buccal and lingual (palatal) pulp horns. Any remaining pulp space was filled with a thermal conducting paste (P3-1). The position of the thermocouples and the tooth thicknesses from the site of laser exposure were measured using periapical radiographs. A periodontal probe with 1mm gradations was placed next to the teeth to verify any magnification error. Each tooth was placed in a 37 °C water bath⁷ with the crown exposed to the

⁷ Braun Inc., Melsungen, Argentina.

atmosphere to simulate oral temperature and humidity as in the intra-oral environment (P3-3).

The model dLase300 - pulsed Nd:YAG (American Dental) laser with an emission wavelength of 1064nm, and a pulse duration of 150 microseconds, was used in this study. A 9mm² area (P3-4; using a standardised template) on the cervical half of buccal and lingual surfaces of 110 teeth were subjected to 11 energy parameter combinations (range of average power 0.3 - 1.50W, and frequency 10-20 Hz) from a pulsed Nd:YAG laser for 2 mins per surface, directly opposite to the embedded thermocouples. Laser energy was delivered through a 320 micron optic fibre in a roving contact motion (manual speed about 3mm/sec) and followed the procedure as in clinical induction of anaesthesia. A 30 second break was allowed for changing application sides.

Ten teeth were allocated for each laser parameter combination. Each trial was replicated at least twice. The average power output was recorded using a power metre (Ophir model S/N 7523, head: 30A,150) before each laser application (onto buccal surface).

Thermocouples with a multi-channel chart recorder⁸ (Yokogawa LR4110) were used to continuously record the temperature changes, at a

⁸ Yokogawa Inc., Tokyo, Japan.

rate of 1mm/sec (P3-5), during the entire study. The first two channels were connected to two K-type bead thermocouples (diameter 0.7mm, accuracy 0.1 °C) which were placed against the pulp horns directly opposite the laser exposure sites. The third channel was used to record the water bath temperature. The thermocouples were calibrated and set at 37 °C, the baseline temperature. Recordings of the temperature were continued after 4mins of lasing, until the sample had cooled down to baseline temperature. The maximum temperature rise of both thermocouples (the maximum temperature recorded during the trial, and the different between baseline temperature), the time to reach the maximum temperatures (calculated from the start of lasing), and the time to cool to baseline temperature (after the termination of lasing) were recorded and analysed statistically.

3.3. Results

The complete experimental data of all the specimens are listed in Appendix IIa. Fig 3.a. illustrates a typical plot of temperature changes as a function of time, with laser energy parameter of 0.95W, 20Hz, from both buccal and lingual thermocouples.

It demonstrates a plateau profile, where the temperature has increased as a function of time before it reached and stabilised around the highest

temperature. Then, it was sustained around this maximum temperature until the termination of lasing. After the termination of lasing, the temperature returned to baseline value in a hyperbolic manner. The cooling of the buccal thermocouples was delayed with the lasing of the adjacent (lingual) thermocouples. Similarly, there was a consistent delay of 10secs between the start of laser exposure and any observable increase in pulpal temperature. Presumably, this delay was attributable to the thermal diffusivity of the teeth and dissipation of surface heat.

Table 3a. lists the mean values of the time to reach the maximum temperature (B-tmax, L-max), the maximum temperatures (B-tmax, L-tmax) and the returning time (B-t return, L-t return) to the baseline temperature of both thermocouples at various energy parameters. The mean tooth thicknesses were 2.95mm from buccal and 2.89mm from lingual surfaces over a 9mm² area. Using the Spearman's Rho correlation ($P < 0.05$), a statistical association between laser power and the time required to reach the plateau temperature, the maximum temperature rise from both thermocouples, the time to return to baseline value at the termination of laser emission at various frequency, has been shown (Appendix IIb). The mean time taken to reach the plateau temperature, for less than 5.5°C of various energy parameters, were 61.3sec and 52.8sec from buccal and lingual/palatal thermocouples respectively.

The temperature profiles recorded from both buccal and lingual thermocouples were similar. However, using the paired t-test, there was significant difference ($P < 0.05$) between the maximum temperature recorded from the buccal and lingual thermocouples.

Figure 3b. shows a linear relationships between the mean maximum temperature rise and laser power, at various frequencies on the buccal thermocouples. With laser energy parameters below 1.1W at 10Hz, 0.83W at 15Hz or 0.7W at 20Hz, and total exposure energy dose of 132J/surface, 87J/surface, and 84J/surface respectively, the mean temperature rise was below the thermal safety limit as previously defined (5.5 °C). Linear regression analyses of the relationship between laser power and maximum temperature changes demonstrated that the slope increased with increasing frequency.

3.4. Discussion and conclusion

The risk of thermal, detrimental pulpal injury is recognised as a major limitation to the use of lasers in dentistry. The knowledge of thermal changes at the level of the dental pulp can be used to study the patterns of distribution of laser energies and lateral heat conduction with various laser wavelengths used for irradiation of dental hard tissues.

At 1064 nm wavelength of Nd:YAG laser radiation, there is only a negligible amount absorbed by the enamel (Quintana *et al.*, 1992; White *et al.*, 1991b; White *et al.*, 1992; Launay *et al.*, 1987), and it is widely scattered by dentine (Fries *et al.*, 1993; Spitzer and TenBosch, 1975). The scattering coefficient of dentine is largely dependent on tubule density (TenBosch and Zijp, 1987). Saski *et al.*, (1996) determined the optical properties of human pulp using spectrophotometry and reported that the absorption at 1064 nm for the Nd:YAG laser is less than 1%. This led to the possibility that the distribution of the Nd:YAG laser energy within human tooth is preferentially deposited at the dentino-enamel and pulpo-dentinal junctions. Since the thermal diffusibility of enamel and dentine is relatively low (Braden, 1976), this may cause subsurface heating (Seka *et al.*, 1994) and pulpal warming.

Therefore, in this study, the placement of the thermocouples against the pulpo-dentinal wall was considered most appropriate and accurate to measure the rise in intrapulpal temperature. This gives a relatively good indication of the amount of subsurface heating from the laser energy at the pulpo-dentinal interface before it is cooled down by the pulpal circulatory system.

White *et al.* (1991d), in an *in vitro* study, measured the pulpal temperature changes during pulsed Nd:YAG laser irradiation, using a 200 micron non-contact fibre, at 5mm from the coronal dentine surface. They concluded that for lasers with power of 1W or less, the pulpal temperature rise was less than 6°C for up to 120sec of laser treatment when the remaining dentine thickness was 1mm or greater. Three years later, White *et al.* (1994) re-examined *in vitro* the rise in intrapulpal temperature on a much smaller surface area of 2mm², but on root dentinal surfaces, using a 320 micron contact fibre. They drew similar conclusions except that the temperature rises were within the thermal safety limit when the laser power was within 1W, 10Hz and the lasing time was less than 30sec, with 2mm remaining dentine thickness. The difference in the surface irradiated area and the intrinsic variations in tubule density between coronal and root dentine (Lilja, 1980), may account for the difference in findings from their previous study.

In this study, the intrapulpal temperature changes from a pulsed Nd:YAG laser irradiation over a standardised 9mm² area on buccal and lingual coronal surfaces for 120sec/surface, were examined using laser energy parameters which are recommended by the manufacturers for clinical induction of surgical anaesthesia. The temperature changes followed a plateau profile. Once the maximum temperature was reached, it was

maintained around the same temperature until the termination of emission. This demonstrated a thermo-equilibrium between the heating induced by the laser and the cooling through the heat conduction of the hard tissue, the radiation and convection through air, water and the thermocouples. This thermal profile is expected to be different in real life and is complicated by the tooth thickness and the thermodynamics of the human pulpal circulatory system.

While one cannot directly measure the remaining dentine thickness *in vivo*, under different laser energy parameters, the knowledge of the maximum temperature rise and the time required to reach the plateau temperature is clinically relevant for the prevention of any possible irreversible thermal pulpal injury.

The temperature profiles recorded from both buccal and lingual thermocouples were similar (Fig 3a). However, there was significant difference ($P < 0.05$) between the maximum temperature recorded from the buccal and lingual thermocouples. This is possibly due partly to the fact that some laser energy was lost in the optic fibre (scattered irradiation from the tooth surface may alter the optical characteristics at the fiber tip) and partly the lingual pulp horn is positioned lower than the buccal counterpart and therefore closer to the water (heat sink). This may also cause a difference in the moisture content of the tubules within the

dentinal specimen, resulting in different heat losses due to latent heat of vaporisation.

White *et al.* (1992) studied *in vitro* the thermal profile of pulsed Nd:YAG laser irradiation applied to enamel and dentine, and demonstrated that as the power and the time of exposure increased, both the diameter of the hot spot on the surface and the thermal penetration distance towards the pulp increased. In addition, when the fiberoptic was roved over the surface in a clinical simulation (i.e. with an increase in surface area), both the diameter of hot spot and the thermal penetration distance were significantly less.

In this study, when the mean temperature rise (buccal thermocouples) was plotted against the average power in a line graph, the maximum intrapulpal temperature rise was almost linearly related to the increase in power at various frequencies (Fig 3.b). This is in agreement with the result of the thermal profile study by White *et al.* (1992). The increase of exposure time, even at lower power, can cause an increase in the thermal penetration distance in the pulpal direction which may possibly explain that using lower power of 1.1W at 10 Hz (110 mJ/pulse), or 0.83W at 15Hz (55.3 mJ/pulse) or 0.7W at 20Hz (35 mJ/pulse), over 120sec of exposure can sufficiently raise the intrapulpal temperature to 5.5°C.

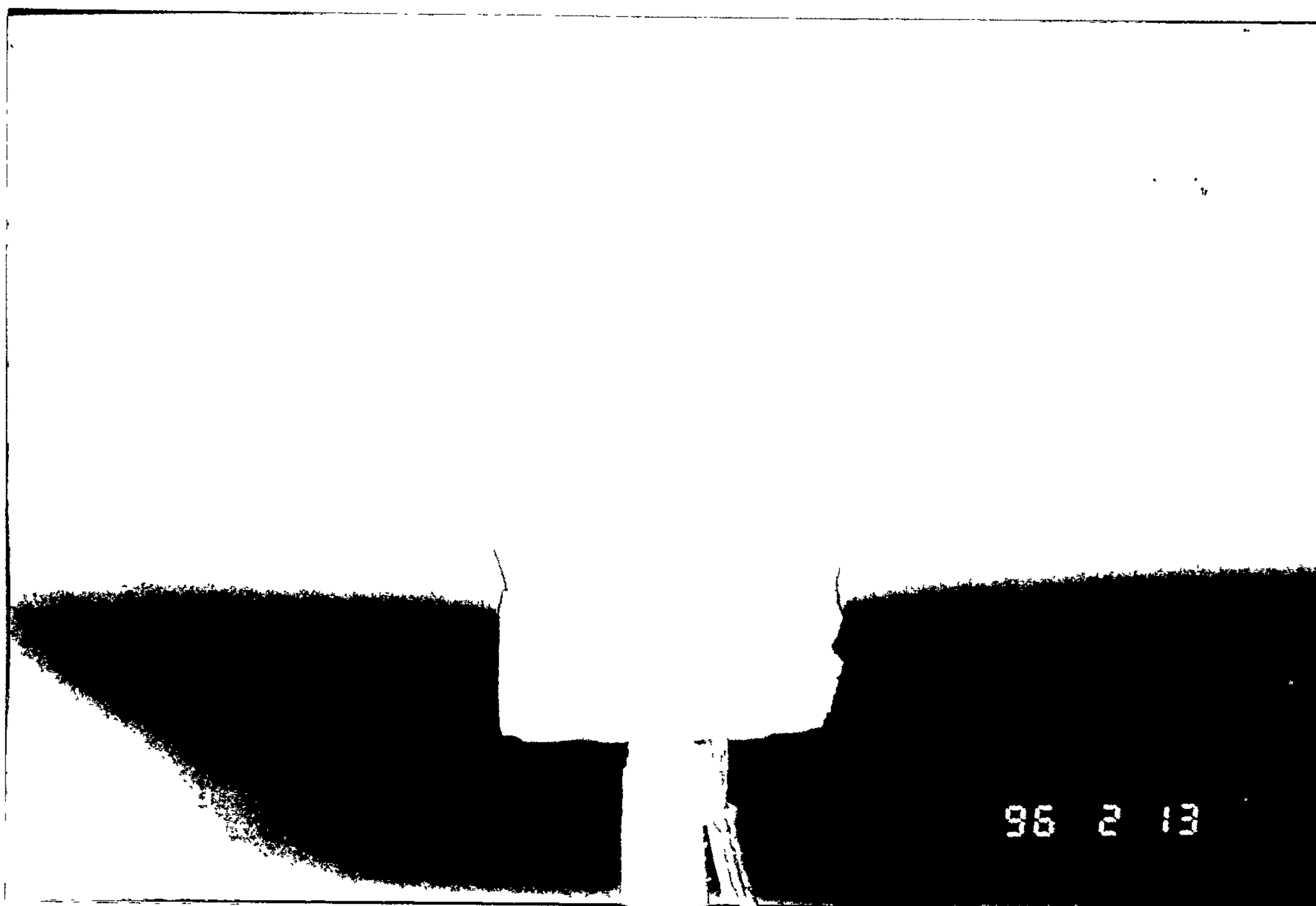
Interestingly, the intrapulpal temperature rise of 5.5°C was achieved using similar power, by increasing the exposure time from 30sec (White *et al.*, 1994) to 120sec (results of this study), and by increasing the irradiated surface area from 2mm² to 9mm². This finding suggested that under prolonged pulsed Nd:YAG laser irradiation, for the same total exposure dose per surface, the size of the irradiated surface area is critical in determining the maximum intrapulpal temperature rise.

This results also indicate that the extent of intrapulpal temperature change is influenced significantly by the frequency applied. That temperature rises for the low frequency modes were less than those for the high frequency modes reflects the increased opportunity for cooling to occur between laser pulses.

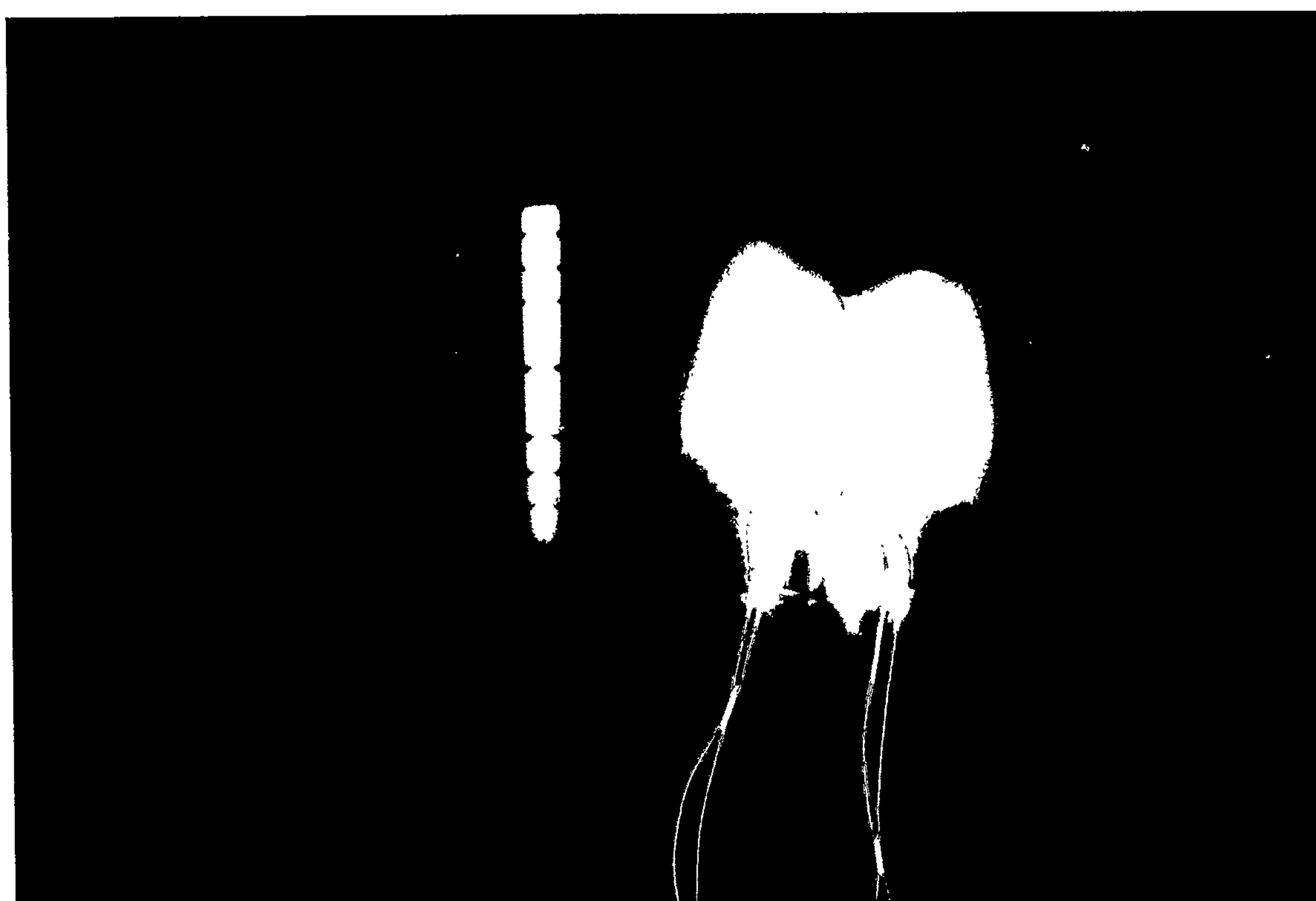
If one uses the energy parameters (power range of 0.75-1.5W, at 15Hz, energy density of 62-124J/cm², total energy dose of 60-120J/surface) recommending by the manufacturers (Myers and McDaniel, 1991) for clinical laser-induction anaesthesia, according to the results of this study, a rise of the intrapulpal temperature beyond the defined safety limit (5.5 °C) is likely. However, in the clinical situation, the thermal changes may be lower than those recorded in the laboratory, because of cooling effects of the microcirculation of the pulp (Michailescu *et al.*, 1995), the periodontium (Kim *et al.*, 1992; Funato *et al.*, 1991) and the saliva. In

addition, with the use of suction or irrigation during laser treatment can further reduce the rise of intrapulpal temperature.

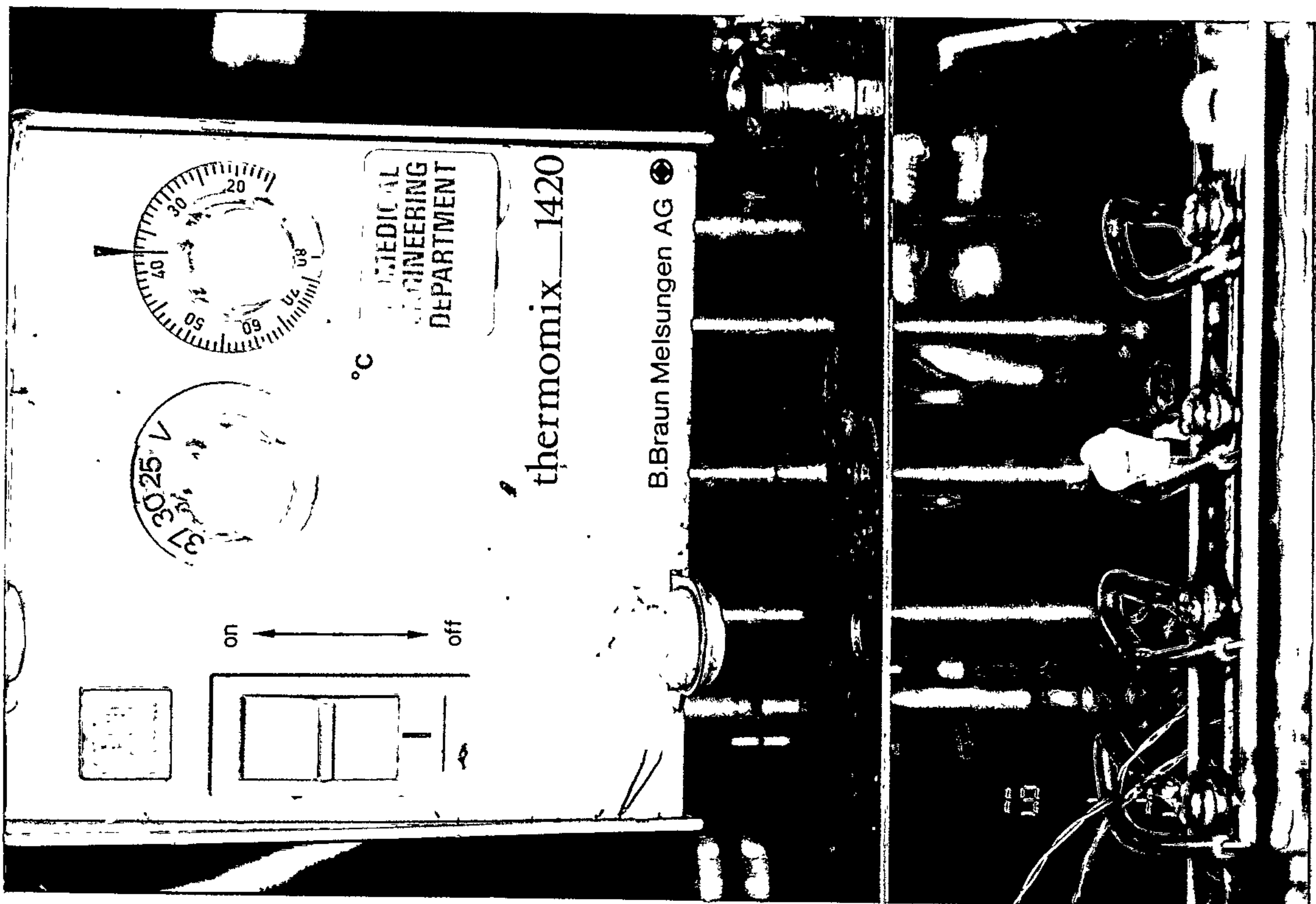
In conclusion, this *in vitro* study showed that prolonged irradiation of pulsed Nd:YAG laser on teeth, as in laser induced clinical pulpal anaesthesia, should not cause devitalising intrapulpal temperature rise, using the energy parameters as defined in this study. However, when a high power level is used, preventive measures such as forms of cooling or modification of the total energy dose per surface area (by either increasing the irradiated surface area or reducing the exposure time per unit area), can increase the thermal safety margin of this wavelength. Whether this may lessen the depth of laser-induced anaesthesia may require further investigation.



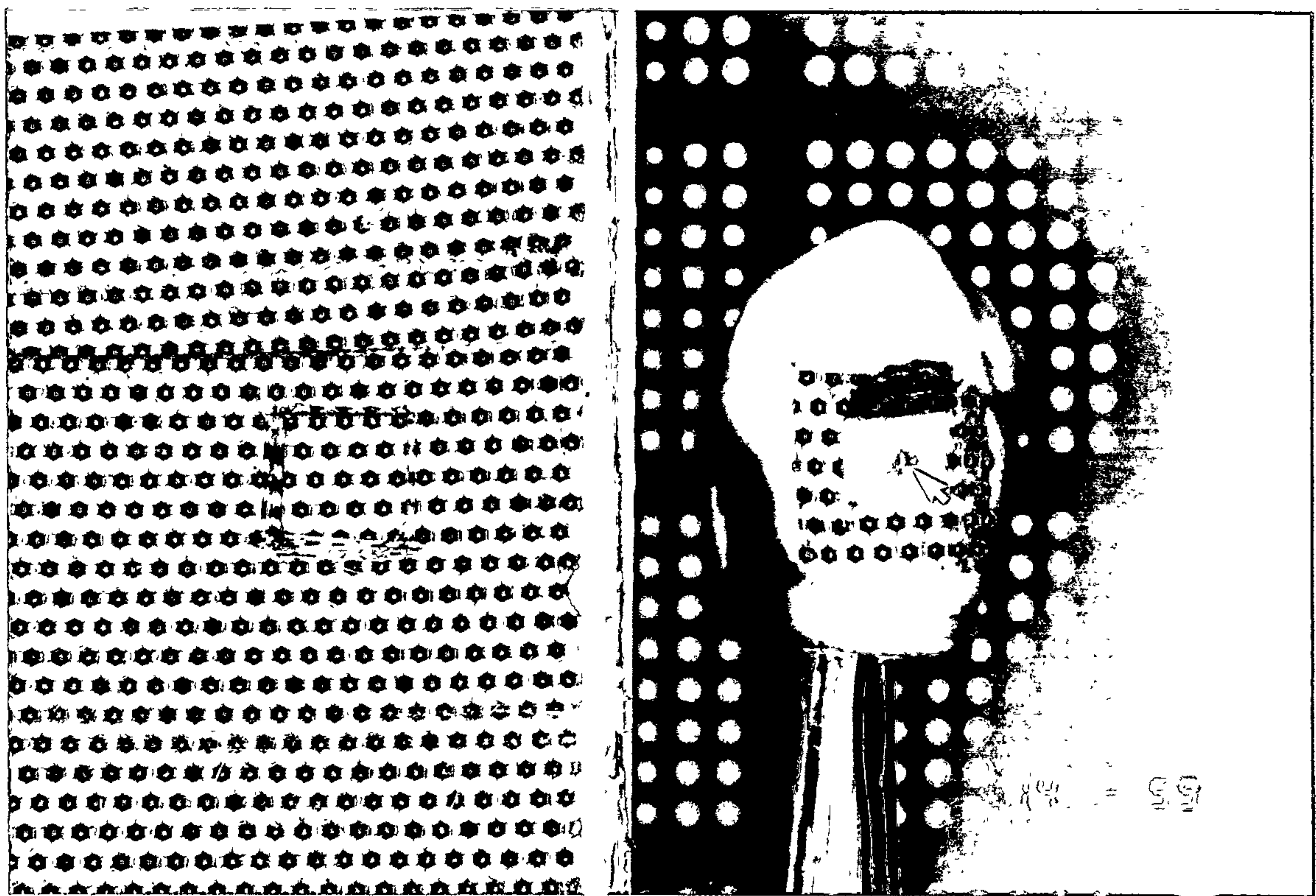
P3-1. This photograph illustrates the tooth with root and pulp being removed and insertion of a K-type thermocouples.



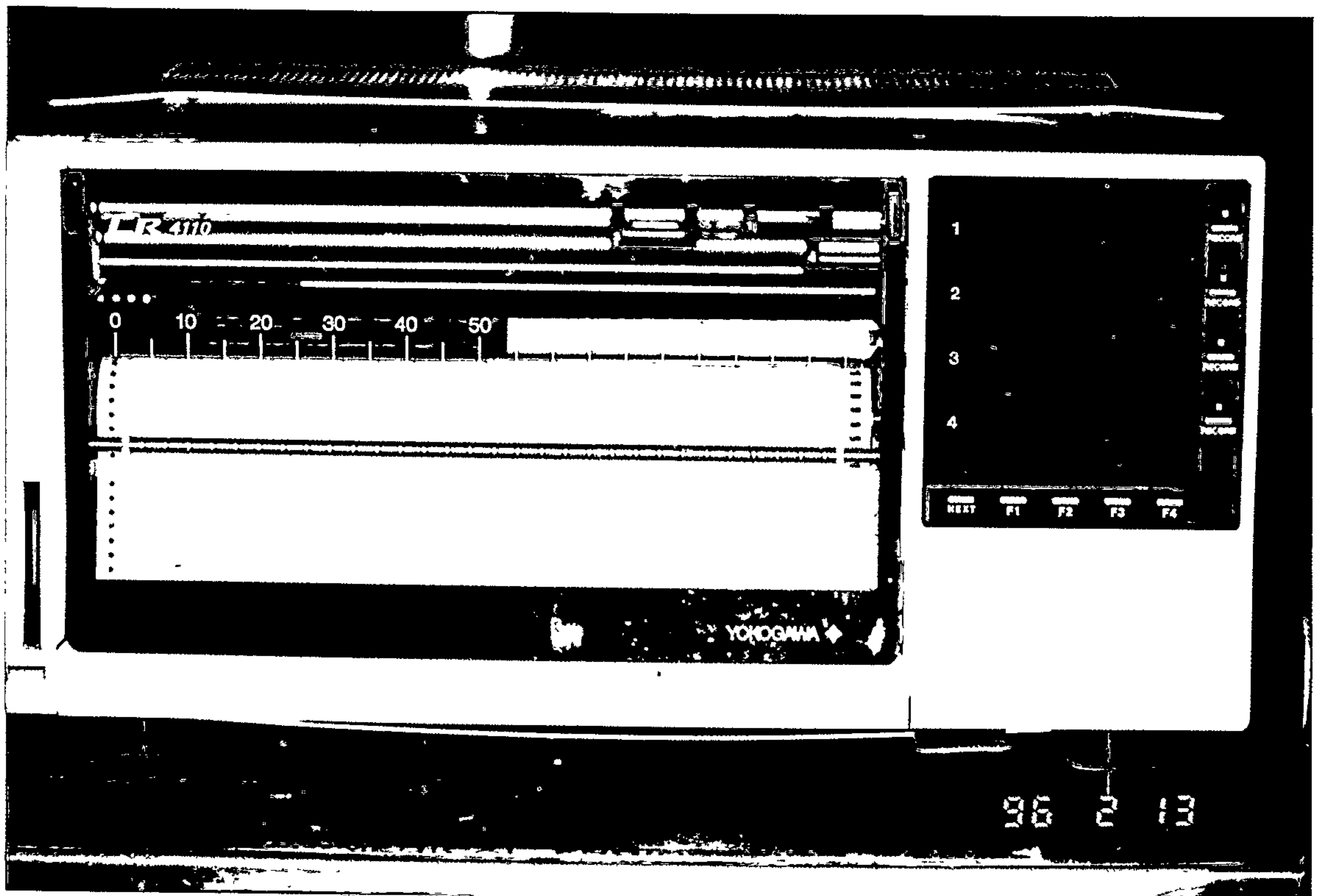
P3-2. This photoradiograph illustrates the position of the thermocouples & the lased tooth thicknesses bucco-lingually. Periodontal probe with imm gradations (left).



P3-3. The test tooth in a 37 °C water bath ⁷ to simulate temperature and humidity of the intra-oral environment.



P3-4. A piece of perspex, with a standardised window (left), being used to construct the template (right) to define the irradiated area (9mm²).The estimated location of the thermocouples (↑).



P3-5. This photograph illustrates a multi-channel chart⁸ recorder (Yokogawa LR4110).

Table 3a. Mean temperature rises and times (with standard deviation) various energy parameters, over 9mm² area, with tooth thickness of 2.95mm from *buccal* & 2.89mm from *lingual* surfaces.

Ave Power W	Frequency pps	B-tmax sec	B-Tmax °C	B-treturn sec	L-tmax sec	L-Tmax °C	L-treturn sec
0.35	10	40±7.3	1.7±0.2	38±19.0	39±6.8	1.6±0.3	34±12.0
0.50	10	46±6.6	2.4±0.3	74±9.0	46±6.5	2.1±0.2	58±3.0
0.75	10	58±12.0	3.8±0.4	96±7.6	53±12.0	3.5±0.4	65±4.5
0.30	15	47±8.0	2.1±0.2	60±5.0	42±8.6	1.9±0.1	49±8.4
0.65	15	64±7.9	4.4±0.4	73±6.0	55±7.7	3.7±0.2	72±7.0
0.95	15	69±15.0	6.3±0.6	93±5.0	59±16.0	5.5±0.9	80±5.0
1.50	15	72±9.8	9.3±0.6	109±15.0	57±9.4	7.2±0.8	82±8.5
0.30	20	61±10.3	2.6±0.5	54±16.0	53±7.7	2.1±0.5	49±12.0
0.50	20	65±12.0	4.0±0.9	70±12.0	50±9.0	2.5±0.8	58±9.0
0.95	20	75±7.7	7.7±0.4	110±12.0	62±7.6	6.7±0.6	93±21.0
1.15	20	77±13.0	9.5±1.3	121±16.0	66±8.0	7.5±1.3	106±17.0

tmax-time to reach max. temperature, Tmax-max. temperature, treturn-recovery time to baseline temperature

Fig 3a. Typical plots of Temperature v Time

at power 0.95 W, 20pps, (48mJ/p), demonstrating the temperature plateau, after reaching the maximum temperature from both Thermocouples.

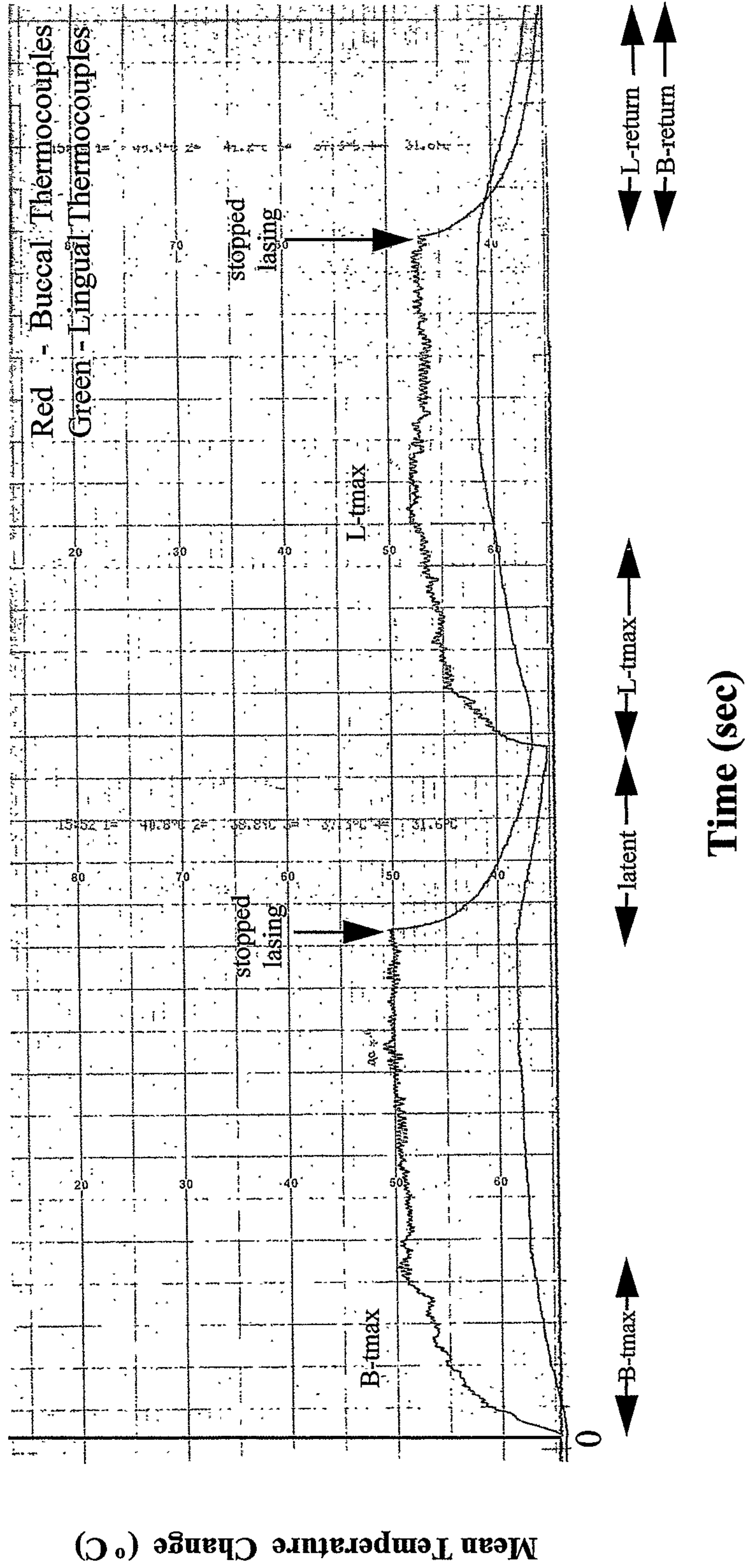
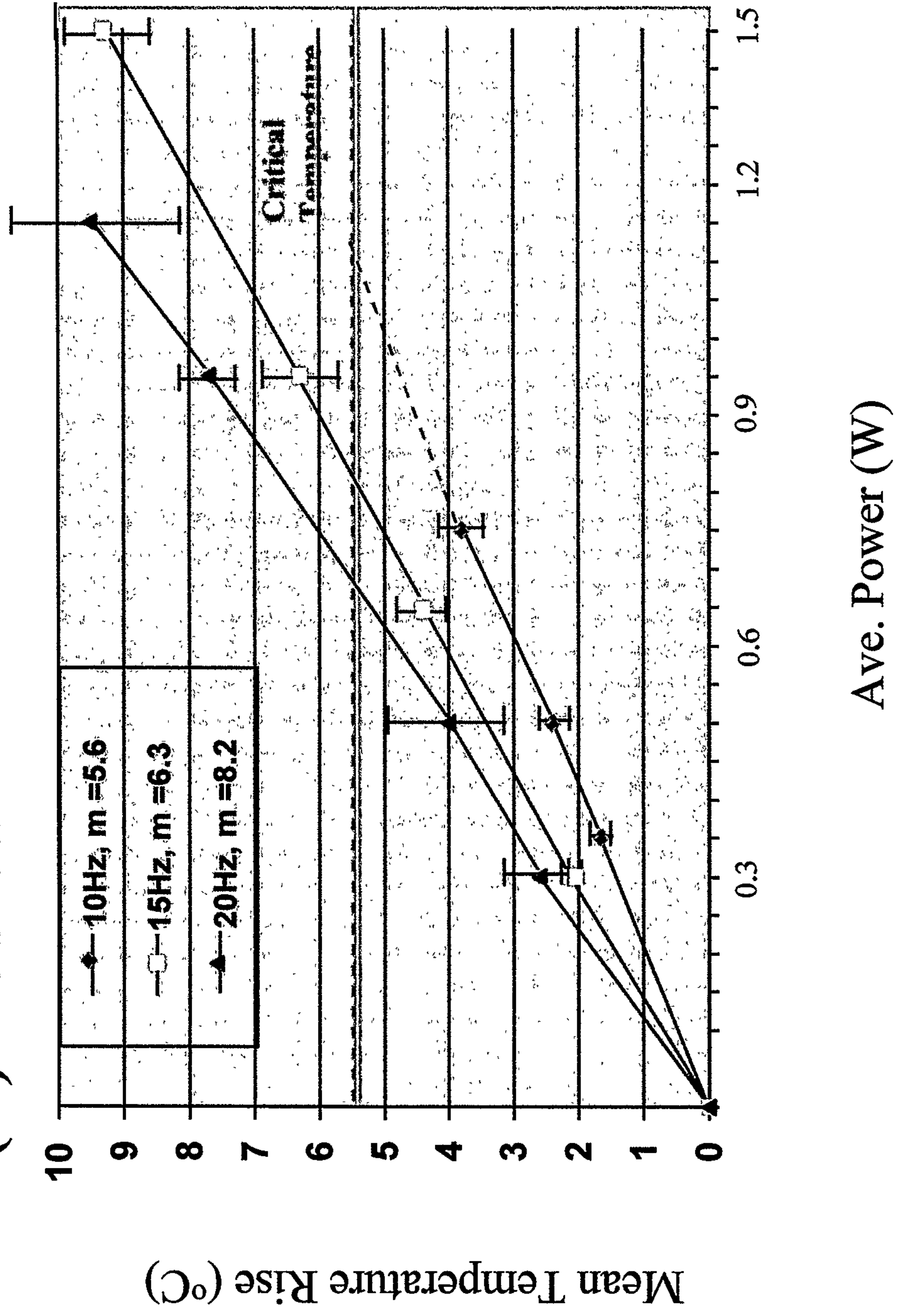


Fig. 3.b. Linear regression analysis of the relationships among power, frequency and temperature rise (buccal thermocouples). Values for gradients (m) are shown in the inset.



4. Tooth temperature changes during pulsed Er:YAG laser ablation. An *in vitro* study.

4.1. Introduction and aims

In recent years, numerous studies have been undertaken to investigate the possible use of the Er:YAG laser in dental and oral surgery as an alternative or adjunct to the mechanical drill. Since the Er:YAG laser has an emission wavelength of 2.94 micron, it is very close to the infrared peaks of the water and hydroxyapatite (hydroxyl group) absorption curves. This makes it readily absorbed by water and hydroxyapatite, which are constituents of dental hard tissues (Walsh and Deutsch, 1989; Wigdor *et al.*, 1993). It has been hypothesised that Er:YAG laser energy induces water vapour expansion inside the tissue causing internal microexplosions and fragmentation of dental hard tissue (Hibst and Keller, 1993). Among the published studies, special attention has been paid to optimising laser ablation efficiency and minimising thermal detrimental side effects. Studies (Hibst and Keller, 1990; Wigdor *et al.*, 1993) have suggested that using higher pulse energy and pulse repetition rates produce higher ablation efficiencies but this will also increase the detrimental thermal side effects on tissues. It is recognised that an intrapulpal temperature rise of 5.5 °C or greater, for more than a minute,

can lead to necrosis of the dental pulp (Zach and Cohen, 1965). Measurements of the rise in intrapulpal temperature (with a thermocouple placed in the pulp) while exposing tooth enamel and dentine to constant laser irradiation, *in vitro*, have demonstrated that multiple pulses of erbium energy can raise the intrapulpal temperature up to 30°C, depending on the remaining tooth thickness (Paghdiwala, 1989) and the presence of water cooling during laser ablation (Burkes *et al.*, 1992; Dostalova *et al.*, 1993; Hibst and Keller, 1993). Steven *et al.* (1996) in an *in vitro* study have shown that with Er:YAG laser energy of 360mJ/pulse, at 10Hz, in the presence of water cooling, at a rate of 4.5ml/min, the temperature rise in the pulp is less than 3°C. Similarly, Lukac *et al.* (1995) in an *in_vivo* animal study of the effects of Er:YAG laser irradiation on teeth have claimed that energies below 300mJ/pulse, at 10Hz, with water cooling caused no significant thermal damage to the adjacent hard tissues and dental pulp. A newly developed Fotona Twinlight laser, a two laser system, which is composed of a 5W pulsed Er:YAG and a 8W pulsed Nd:YAG laser, is claimed to cut cavities without heat.

The purpose of this *in vitro* study was to test this claim by measuring the intrapulpal temperature change during the pulsed Er:YAG laser hard tissues ablation, using the Fotona Twinlight laser⁹ (P4-1),

at the highest energy available (500mJ/pulse), and to compare these changes with Nd:YAG laser irradiation and highspeed bur cavity preparation on extracted human premolar teeth.

4.2. Materials and methods

a) Tooth preparations

Recently extracted human (caries-free) premolar teeth that were removed for orthodontic reasons were collected and stored in an aqueous 0.2% thymol solution to inhibit bacterial growth until used. The teeth were sectioned horizontally to remove the apical two-third portion of the root, using a diamond saw. The pulp contents were removed to allow placement of the thermocouples into the pulp chamber.

Two thermocouples were secured so as to be in contact with the internal dentinal surface of buccal and lingual (palatal) pulp horns, with the use of wooden sticks. The remaining pulp space was filled with a thermal conducting paste. Position of the thermocouples and the tooth thicknesses from the site of laser exposure to the pulp were measured using a periapical radiograph of each tooth. A periodontal probe with 1mm gradations was placed next to the tooth to determine any magnification error (P4-2).

⁹ Emona technologies Inc., NSW, Australia.

Each tooth was placed in a 37°C water bath with the crown exposed to the atmosphere through a rubber dam to simulate the thermal environment of a natural tooth in an open mouth (P4-3).

b) Laser equipment

A 2mm² area (P4-4) on the mesial or distal surfaces of 13 teeth was then subjected to 100mJ, 10Hz pulses from an Nd:YAG laser for 60sec., then 500mJ, 10Hz pulses from an Er:YAG laser with water cooling (at a rate of 8 ml/min) for 60sec. A cavity was cut with a highspeed bur (NSK, ALPHA-AIR A6619) under both air and water coolant, at the rate of 8ml/min. Using a 0919 diamond flat fissure bur, preparations were cut into a 2mm² area which was previously irradiated with the pulsed Nd:YAG laser, on the proximal surface of six randomly selected teeth, for 60sec.

The Fotona Twinlight: 5W pulsed Er:YAG and 8W pulsed Nd:YAG lasers were used in this study. In this system, the 294nm Er:YAG laser has a pulse width between 200-400 microsecond, and operates 1cm from the test surface with an articulating arm delivery system. The 1064nm Nd:YAG laser has a pulse width between 125-160 microseconds and operates in contact mode, with a fiberoptic (320 micron) delivery system.

c) Temperature measurements

Thermocouples with a multi-channel chart recorder (Yokogawa LR4110) were used to record continuously the temperature changes, at a rate of 1mm/sec, during the entire laser study. The first two channels were connected to two K-type bead thermocouples (diameter 0.7mm, accuracy 0.1°C.) which were placed against the pulp horns directly opposite the laser exposure site. The third channel was used to record the water bath temperature. The thermocouple was calibrated and set at 37°C, as the baseline temperature. Recordings of the temperature were continued after lasing, until the sample had cooled down to baseline temperature.

The mean values at time intervals of 10sec up to 60sec period and the recovery time to baseline were statistically analysed using student's paired t-test. An analysis of variance was used to determine the significance of any differences observed.

4.3. Results

Appendix IIIa. lists the complete experimental data. Table 4.a. shows the mean pulpal temperature rise (with standard deviation) at 10second intervals and the recovery time of the three test agents. A histogram (Fig 4.a) illustrates the results of the mean temperature changes with time from three individual groups. this shows that there was a gradual increase

of intrapulpal temperature as a function of time in both Nd:YAG laser and highspeed groups. There was an initial drop in temperature at the first 10sec in the highspeed group; perhaps this was the result from the effects of both air and water cooling. In the Er:YAG group, the rises seemed to stabilise around 2 °C after 20sec. There was a slight drop of the recorded mean temperature of 0.5 °C towards the termination of lasing; this may be due to exposure of pulp chamber allowing additional water cooling. The rise in pulpal temperature over 60secs for the Nd:YAG laser and highspeed drill were 7.9 °C (S.E. 0.53) and 3.6 °C (S.E. 0.2) respectively. The temperature rise in the Nd:YAG laser group was over 5.5°C after 30sec of application.

When the data of the mean temperature changes of the three tested groups were represented in a line graph (Fig 4.b), it further illustrated the recovery time for the temperature return to baseline value after 60secs of applications. The mean recovery time to baseline temperature was 82.7sec (greater than one minute) for the Nd:YAG laser, 36.7sec (approximately half a minute) for the highspeed drill and 2.6secs (almost instantaneous) for the Er:YAG laser.

Statistical analyses (Appendix IIIb), using a paired t-test ($P < 0.05$), showed there was a significant difference between the Nd:YAG laser and the other two groups in terms of changes in temperature and recovery

time. Using analysis of variance ($P < 0.05$), it was shown that the pulpal temperature change was not significant between Er:YAG laser and highspeed groups. However, there was a significant difference between their recovery times. The large variation found for the drill samples may be a result of the difficulty in achieving stability and a uniform speed during cavity preparation.

4.4. Discussion and conclusion

Nd:YAG and Er:YAG are infrared lasers and their tissue interactions are influenced by thermal conduction and convection of heat (Koort and Frentzen, 1991;1992). The potential for inducing thermal damage to the adjacent tissues and the underlying pulp depends upon the overall interaction with the water content (for Er:YAG) and pigmentation (for Nd:YAG) in the tissues (Kramer *et al.*, 1990; Arcoria *et al.*, 1994).

This study demonstrated that a 2mm^2 area of tooth surface with tooth thickness of $2.2 \pm 0.2\text{mm}$, when exposed to Nd:YAG laser pulses of 100mJ, at 10Hz. for less than 30sec, will fall within the thermal safety limit as defined by Zach and Cohen (1965). This observation is also comparable with the data which was reported by White *et al.* (1994).

The presence of water cooling during pulsed Er:YAG hard tissues ablation is critical (Burkes *et al.*, 1992; Dostalova *et al.*, 1993; Hibst and

Keller, 1993) for controlling the distribution of Er:YAG laser energy deposited within the tissues. It has been hypothesised that water plays an important role in enhancing of the deposition of energy on the surface layer, and limits conductance to the underlying pulp. This includes wetting the crater between pulses, which prevents consecutive heating of the desiccated surfaces (Hibst and Keller, 1990; 1993), shielding of the tooth surface against the non-ablative parts of the laser beam (Wigdor *et al.*, 1993), and inducing a cavity within the water layer through which the remainder of the pulse can propagate to the tissue surface (Wigdor *et al.*, 1993).

The effects of water cooling during Er:YAG laser ablation can possibly explain why even at an energy of 500mJ per pulse (some five times higher than that of the Nd:YAG pulses), the mean temperature rise was less than 2°C. At the termination of Er:YAG laser exposure, the recovery time to the baseline temperature was rapid, even after direct irradiation of the thermocouples, particularly compared to pulsed Nd:YAG energy.

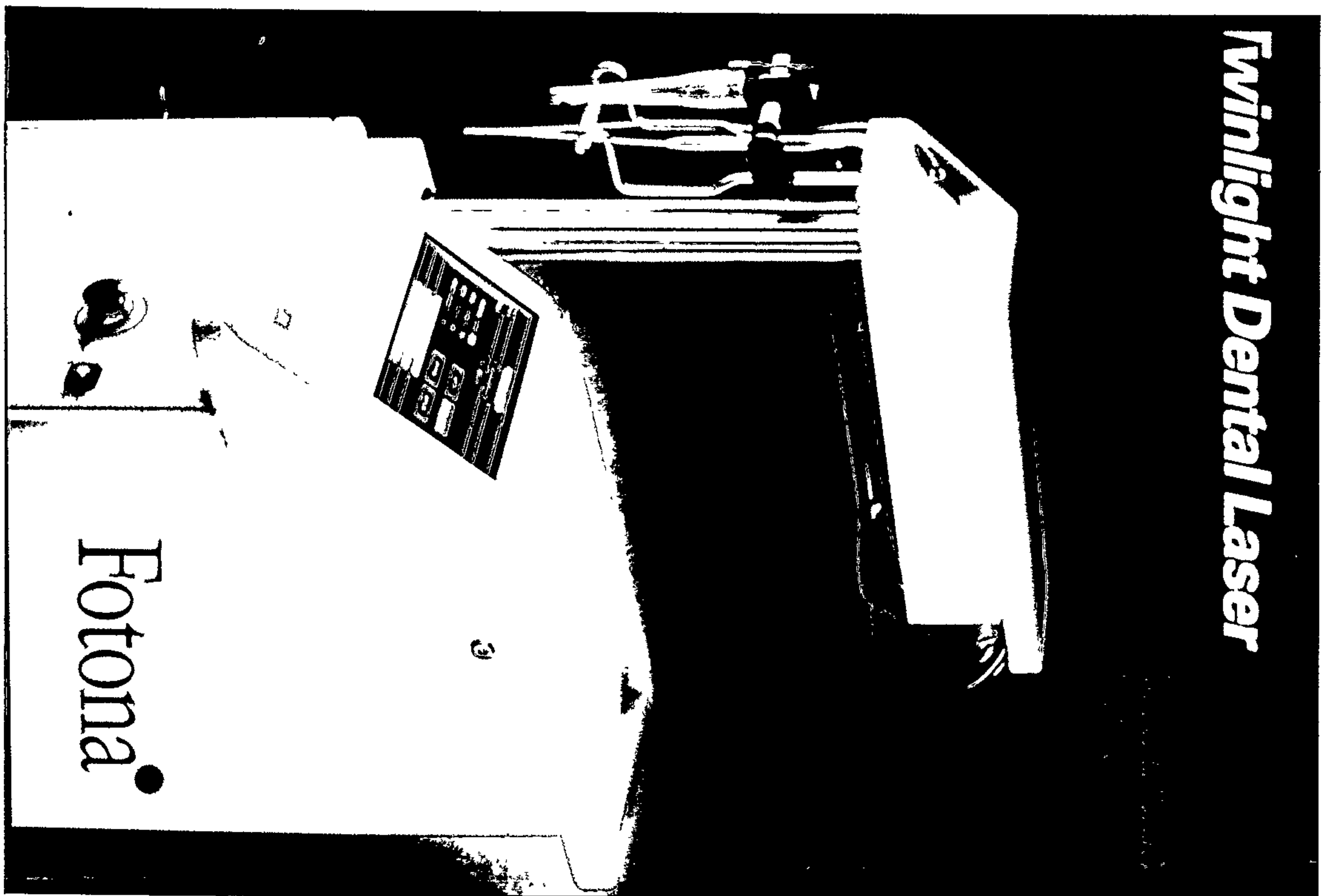
Recent data indicates that a relatively low the water flow rate of 4.5ml/min (Steven *et al.*, 1996) will limit the temperature rise to less than 3°C, even during prolonged ablation at the energy of 360J/pulse, at 10Hz. The results of this pilot study are consistent with this claim, and indicate that at relatively higher energy setting (500mJ per pulse and a higher

cooling rate of 8ml/min), during 60sec of pulsed Er:YAG laser hard tissue ablation, the mean temperature rise was less than 2°C. It also demonstrated that at the termination of Er:YAG laser treatment, the recovery time to the baseline temperature was rapid, even after irradiation directly onto the thermocouples. This gives rise to the question of whether the higher power may need a higher water cooling rate to reduce the pulpal warming effects induced by the laser. This would require further investigation.

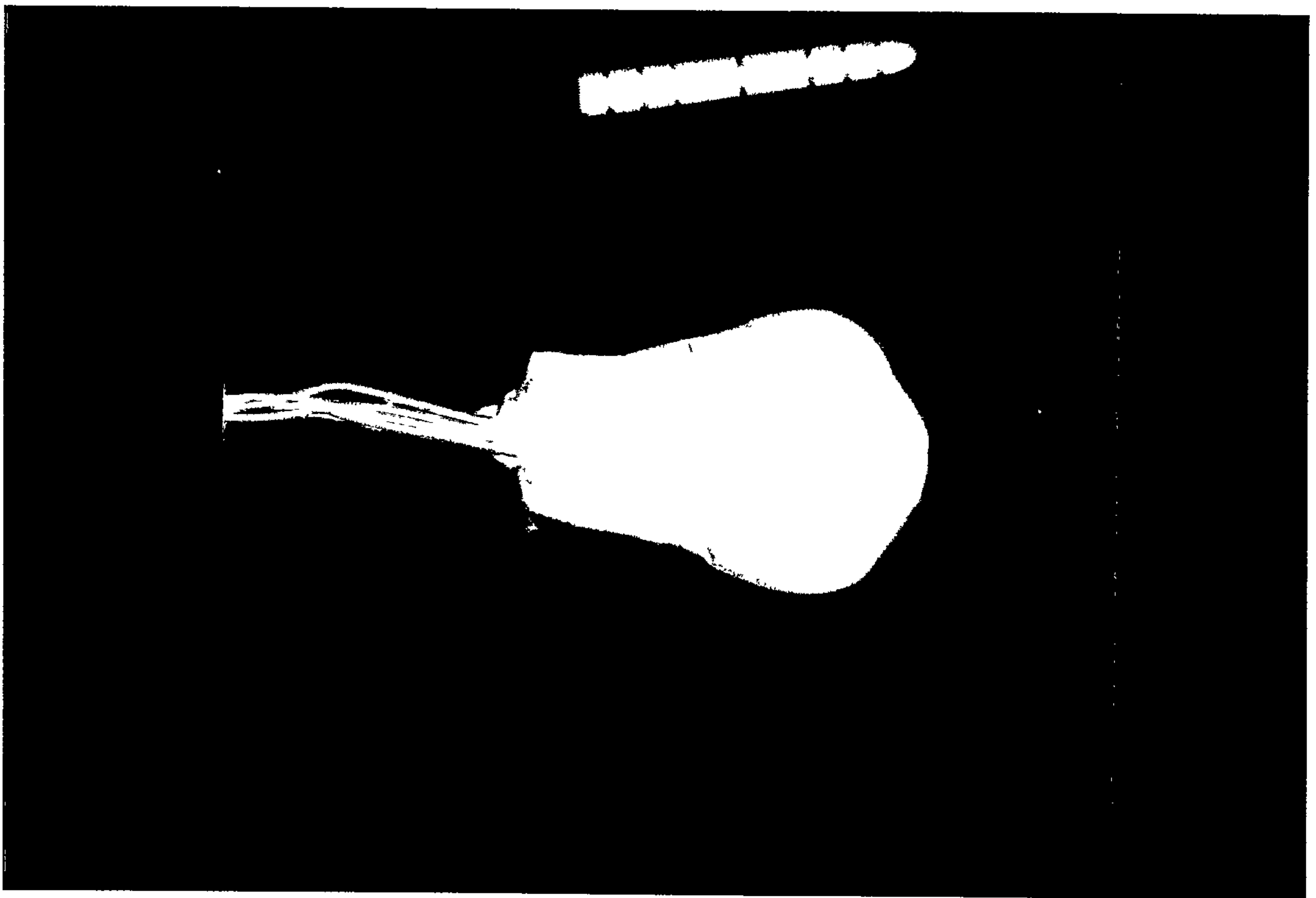
The application of an air-and-water spray simultaneously during Nd:YAG laser irradiation, has been investigated and found to provide adequate heat protection to the pulp, equivalent to that when using the dental drill (Levy, 1991; Miserendino *et al.*, 1993; Abt *et al.*, 1992). Rizioiu *et al.* (1994) has demonstrated that even at laser powers 3-4 times higher than 3W, the rise in the intrapulpal temperature is limited to 2.5 °C, as compared with 12 °C without air-water-cooling. In a histological study, Miserendino *et al.* (1994) confirmed that the use of such a concurrent cooling with the pulsed Nd:YAG laser irradiation on enamel, when exposed to higher power of 12W for 5sec, caused no damage to the pulp. These results suggest that the use of air-water-cooling may alter the thermal profile of pulsed Nd:YAG laser when it is applied to enamel and dentine, through the reduction of both the diameter of hot spots and the

thermal penetration depth (White *et al.*, 1992). The potential use of air-water-cooling simultaneously during pulsed Nd:YAG laser clinical application, especially when higher powers or prolonged exposures are used, should be investigated further.

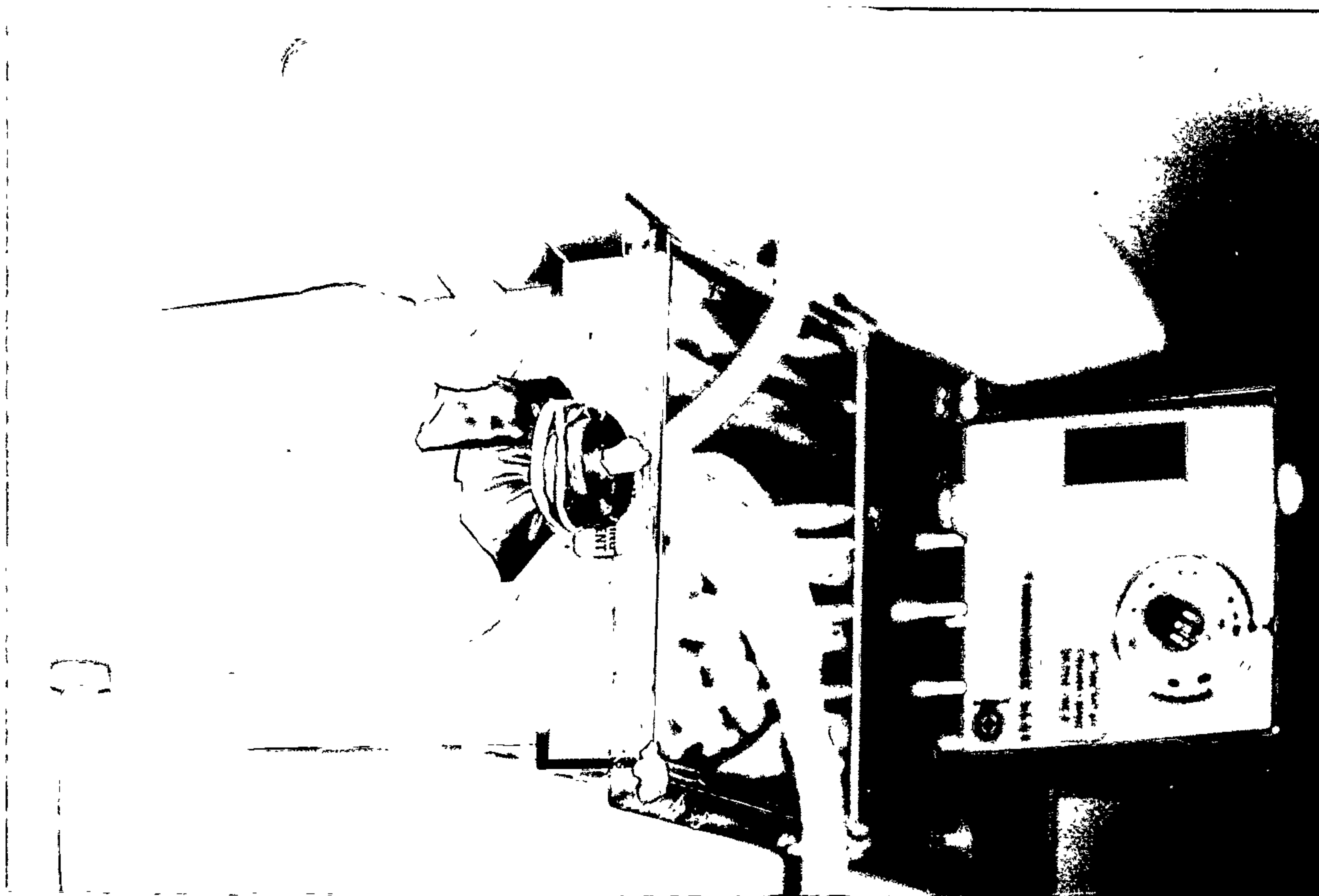
In conclusion, the Er:YAG laser used in the presence of water-cooling has a higher thermal safety margin when compared with the pulsed Nd:YAG laser for hard tissue application.



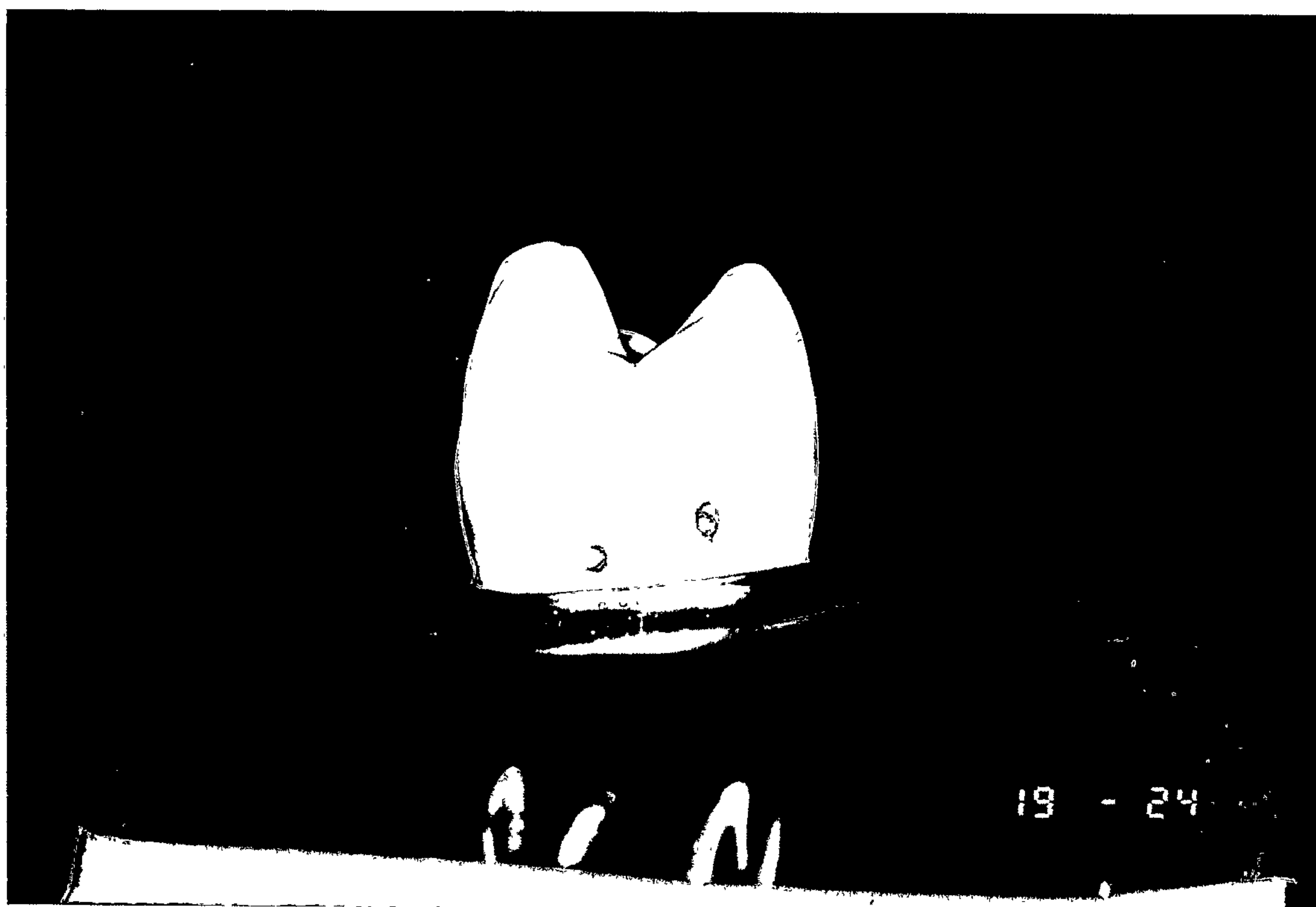
P4-1. The Fotona Twinlight laser⁹ which composes of a 5W pulsed Er:YAG and 8W pulsed Nd:YAG lasers



P4-2. This photoradiograph illustrates the position of the thermocouples and the lased tooth (right) thicknesses (meso-distally). Periodontal probe (left).



P4-3. This photograph illustrates the test tooth which was placed on a 37 °C water bath with the crown exposed to the atmosphere.



P4-4. This photograph illustrates the Er:YAG laser (left) and highspeed bur (right) cut cavities, on the proximal surfaces.

Table 4.a. The mean pulpal temperature rise (with standard deviation) and recovery time of the test groups, over a 2mm² area, with tooth thickness of 2.2±0.2mm.

Time (secs)	Nd:YAG	Er:YAG	Highspeed
10	2.8±1.4 °C	0.5±0.6 °C	-1.0±0.5 °C
20	4.6±1.6 °C	2.0±1.2 °C	0.9±1.3 °C
30	5.9±2.0 °C	1.9±1.1 °C	3.0±1.4 °C
40	6.7±2.3 °C	1.9±1.2 °C	3.3±1.3 °C
50	7.3±2.6 °C	1.9±1.1 °C	3.4±1.2 °C
60	7.9±2.8 °C	1.4±1.1 °C	3.6±1.2 °C
Recovery time	82.7±29.9sec	2.6±1.5sec	36.7±8.2sec

Fig.4.2. Mean Temperature Change vs Time

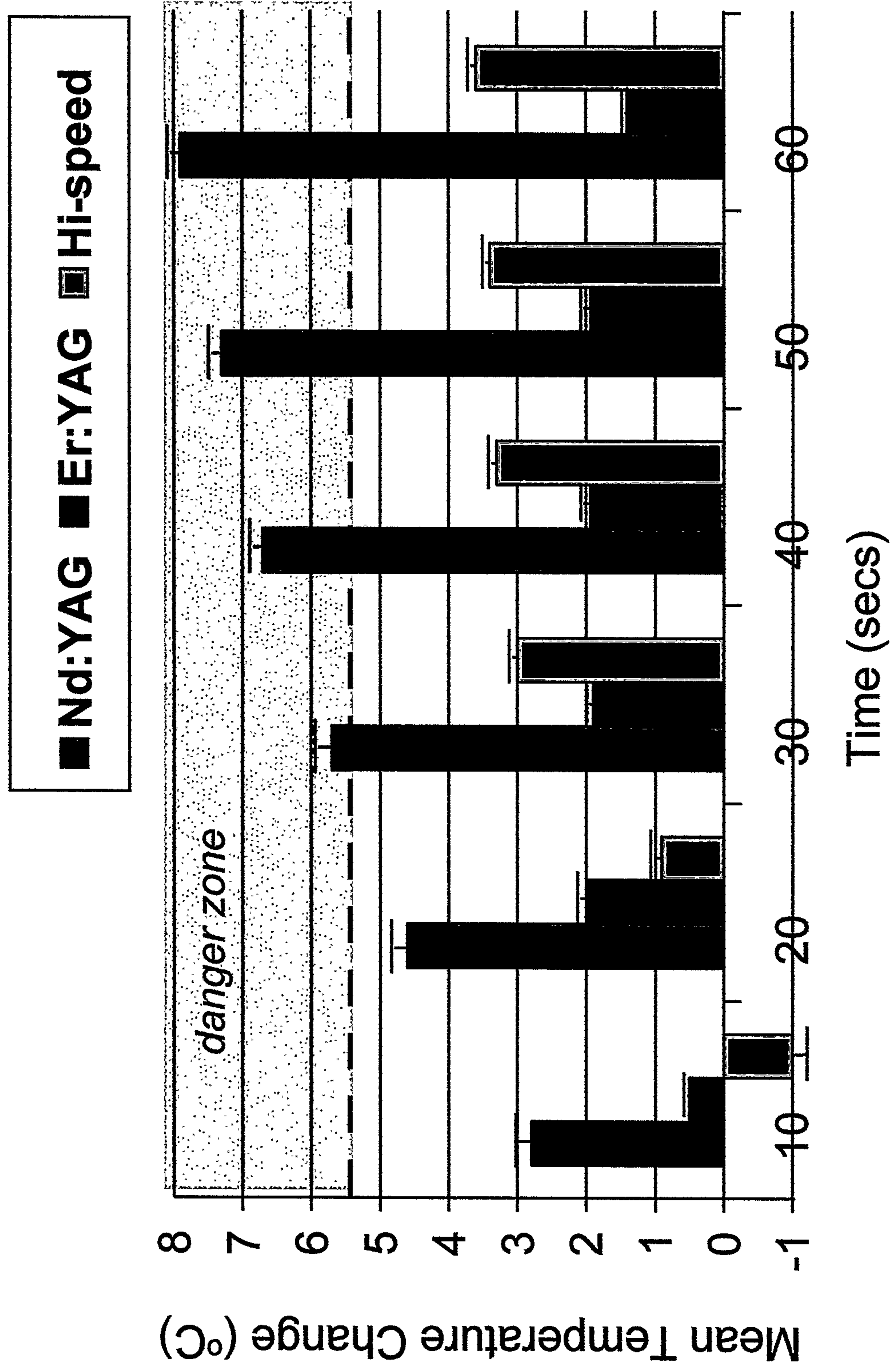
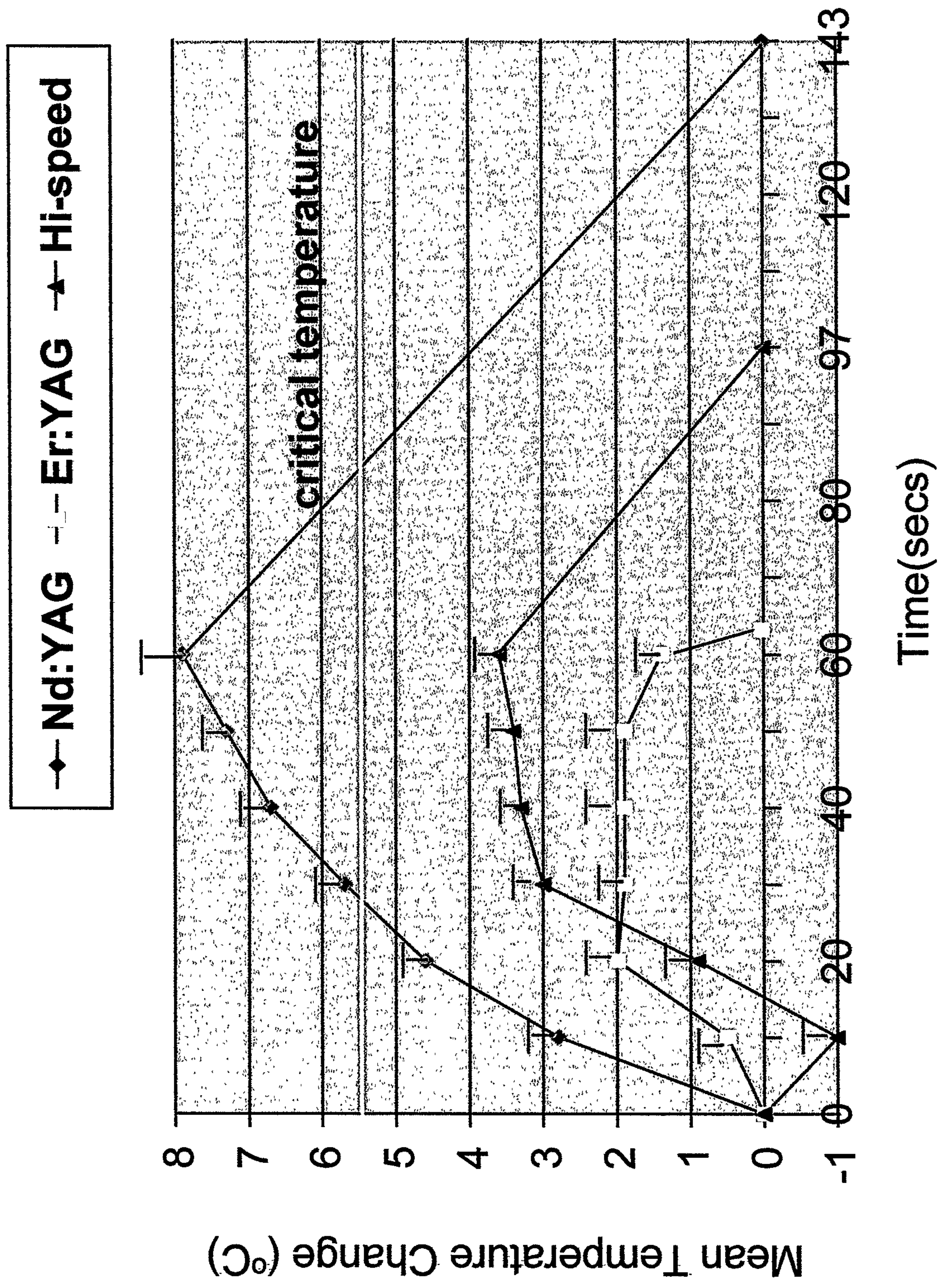


Fig.4.b. Mean Temperature Change vs Time



5. The rise in intrapulpal temperatures: Bluelines vs multilines argon lasers. An *in vitro* study.

5.1. Introduction and aim

The photo-absorption spectrum of light activated restorative materials has its peak at 480nm (Cook, 1982). The argon laser emits several wavelengths, namely the blue singleline (primarily 476 & 488nm) and the blue-green multilines (primarily 476, 488 & 514nm), allowing the laser to activate photopolymerization of dental resin materials (Severin and Maquon, 1989). The argon laser can polymerise composite resins at a faster rate (Blankenau *et al.*, 1991; Kelsey *et al.*, 1992) and give better physical properties of the cured resins compared to the traditional visible light source (Blankenau *et al.*, 1994; Blankenau *et al.*, 1993; Kelsey *et al.*, 1989; Matsutani *et al.*, 1990) and this has been well documented.

A recent study (Powell *et al.*, 1993) has shown it is safe to irradiate enamel with an argon laser with an energy density less than 900J/cm², as this results in no irreversible pulpal or visible enamel damages, and the change in intrapulpal temperature is less than 6°F.

It has been demonstrated that the blue singleline and blue-green multilines are comparable in terms of the diametral tensile strength of the cured resins (Powell and Blankenau, 1994).

The object of this *in vitro* study was to compare the rise in intrapulpal temperature (at different energy densities) of blue singleline with the blue-green multilines argon laser and to correlate any findings with those following the application of Nd:YAG lasers.

5.2. Materials and methods

Fifty human, caries free premolar teeth, recently extracted for orthodontic reasons, were sectioned horizontally at the cemento-enamel junction. The pulpal content was removed and K-type bead thermocouples were embedded with thermopaste into the pulp chamber, directly opposite the buccal laser exposure site. The tooth thicknesses (mean: $2.8 \pm 0.2\text{mm}$) from the site of laser exposure to the thermocouples were determined radiographically. The prepared teeth were secured with the crowns above the water level, in a water bath at 37°C to simulate intraoral temperature (P5-1) and humidity (Dostalova *et al.*, 1993; White *et al.*, 1994). The argon laser, an HGM¹⁰ model Dental Spectrum 400, which emits both blue line and blue-green multilines and equipped with fiberoptic delivery system (600 micron fibre), was used in this study (P5-2).

¹⁰ HGM, inc. Salt Lake City, Utah, USA.

Each tooth received both bluelines and blue-green multilines argon lasers, alternately, in a random manner, with a selected spot size (range : 1-5mm), at an average power of 0.6W, continuously for 20sec. The teeth were randomly placed into groups of 10 teeth for each spot size. The laser optical fibre was stabilised by rigid positioning jig. The templates (P5-3) with circle having diameters which correspond to the various spot sizes (range : 1-5mm) were placed against the tooth to set the distance between the fibre and the irradiated tooth surface. The changes in temperature from the baseline were continuously recorded with a chart recorder (Yokogawa LR4110), at a rate of 1mm/sec (P3-5).

5.3. Results

Appendix IVa. lists the complete experimental data. The results showed a gradual increase in temperature a decrease in spot size (or irradiated surface area) and an increase in laser exposure time. Table 5.a. shows the mean pulpal temperature rise (with standard deviation) for bluelines versus blue-green multilines argon laser, at 5sec interval, with mean tooth thickness of 2.8 ± 0.2 mm.

With an exposure time of less than 15sec, at 0.6W average power, with spot sizes ranging from 1mm to 5mm (ie. energy density $< 900\text{J/cm}^2$), the mean temperature rises of both bluelines (Fig. 5.a) and blue-green

multilines (Fig. 5.b) argon laser wavelengths, were less than the critical temperature of 5.5 °C.

Statistical analysis (Appendix IVb) using the paired t-test showed significant differences ($P < 0.05$) between blue-line and blue-green multiline wavelengths in terms of changes in intrapulpal temperature for all spot sizes. The mean temperature rise of the blue-line readings was 1°C higher than the blue-green multilines readings.

5.4. Discussion and conclusion

Researchers (Swartz *et al.*, 1983; Forsten, 1984) have demonstrated the ability of visible light to penetrate both composite material and tooth structure to photopolymerize camphorquinone-activated resins. It has been postulated that trans-enamel polymerisation of resin can enhance marginal seal and minimise shrinkage (Weaver *et al.*, 1988). However, there has been concerns that high intensity light energy may cause pulpal warming and lead to pulpal damage (Thompson *et al.*, 1996). The result of this study is concurrent with the argon laser oral safety parameters defined by Powell *et al.* (1993) for teeth (energy density $< 900 \text{ J/cm}^2$).

Moreover, within an exposure time of less than 15sec, at 0.6W average power of both blue-line and blue-green multiline laser wavelengths and with the laser beam at least 1mm from the tooth surface, with mean tooth

thickness of 2.8 ± 0.2 mm, the rise in intrapulpal temperature is less than 5.5°C , in the absence any form of cooling such as the circulatory cooling effect from the intact human pulp. This safety parameter is clinically relevant for the prevention of any possible pulpal damage when the laser is used for trans-enamel polymerisation of resin.

In this study, the results showed that the rise in pulpal temperature (pulpal warming) is a function of irradiated surface area and the total exposure dose of a argon laser energy. Studies (Spitzer and TenBosch, 1975; Seka *et al.*, 1994) have shown that lasers in the visible (argon) and near infrared (Nd:YAG) region of the electromagnetic spectrum have similar optical properties in relation to dental hard tissues, and can penetrate deeply into the pulp (Fried *et al.*, 1993) to induce pulpal warming (Stern *et al.*, 1969; Adrian *et al.*, 1971; Serebro *et al.*, 1987; Melcer *et al.*, 1987; Renneboog-Squilbin *et al.*, 1989; Arcoria *et al.*, 1991).

One may imply from this correlation that the effects of pulpal warming induced by the Nd:YAG laser is also a function of the irradiated surface area and the total exposure energy dose.

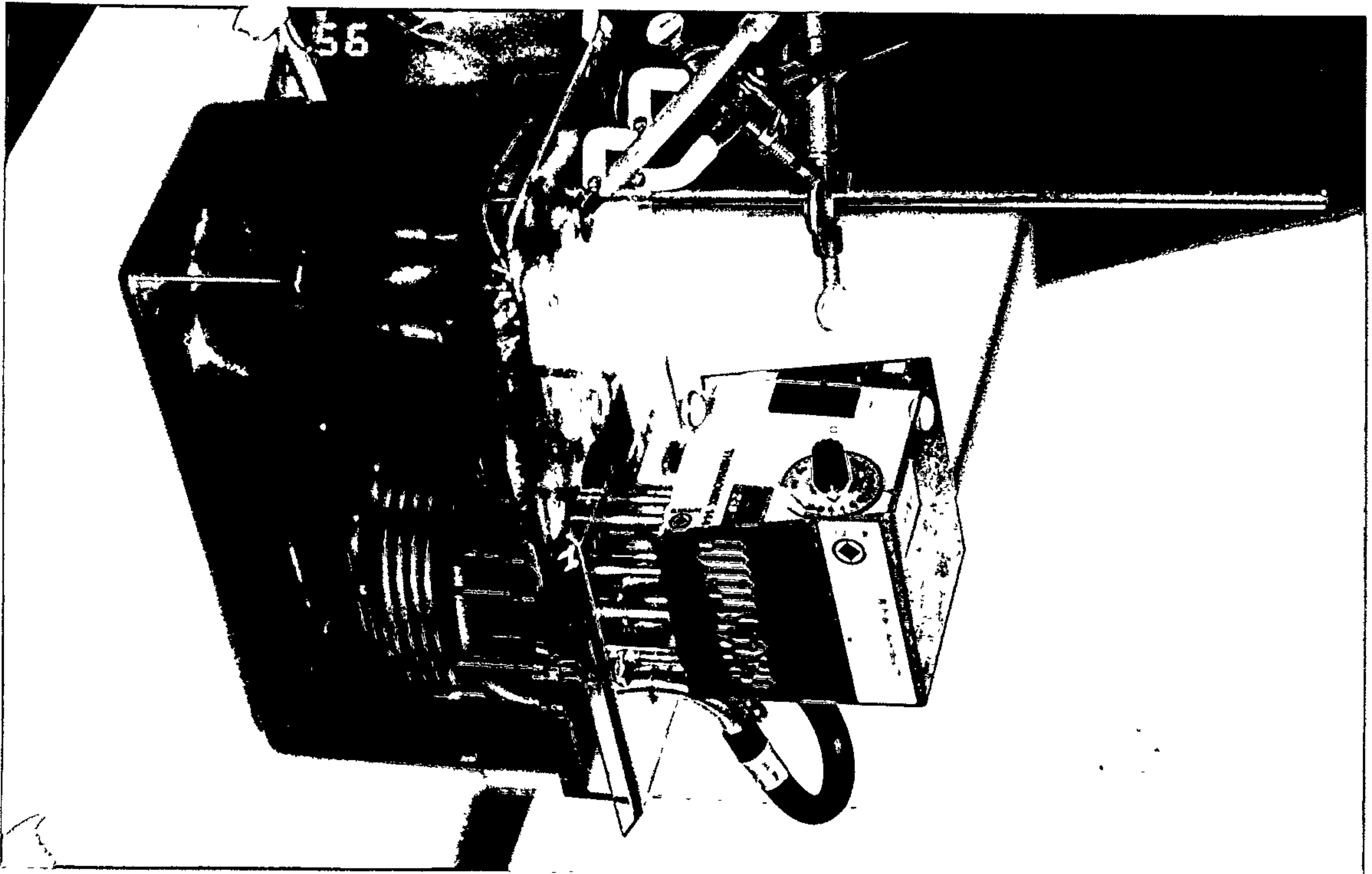
In conclusion, this *in vitro* study has demonstrated that the rise in pulpal temperature (pulpal warming) is a function of irradiated surface area and the total exposure to argon energy. The bluesines cause a greater rise in

intrapulpal temperature than the blue-green multilines of argon lasers, however, the rise is under the critical temperature (5.5 °C).

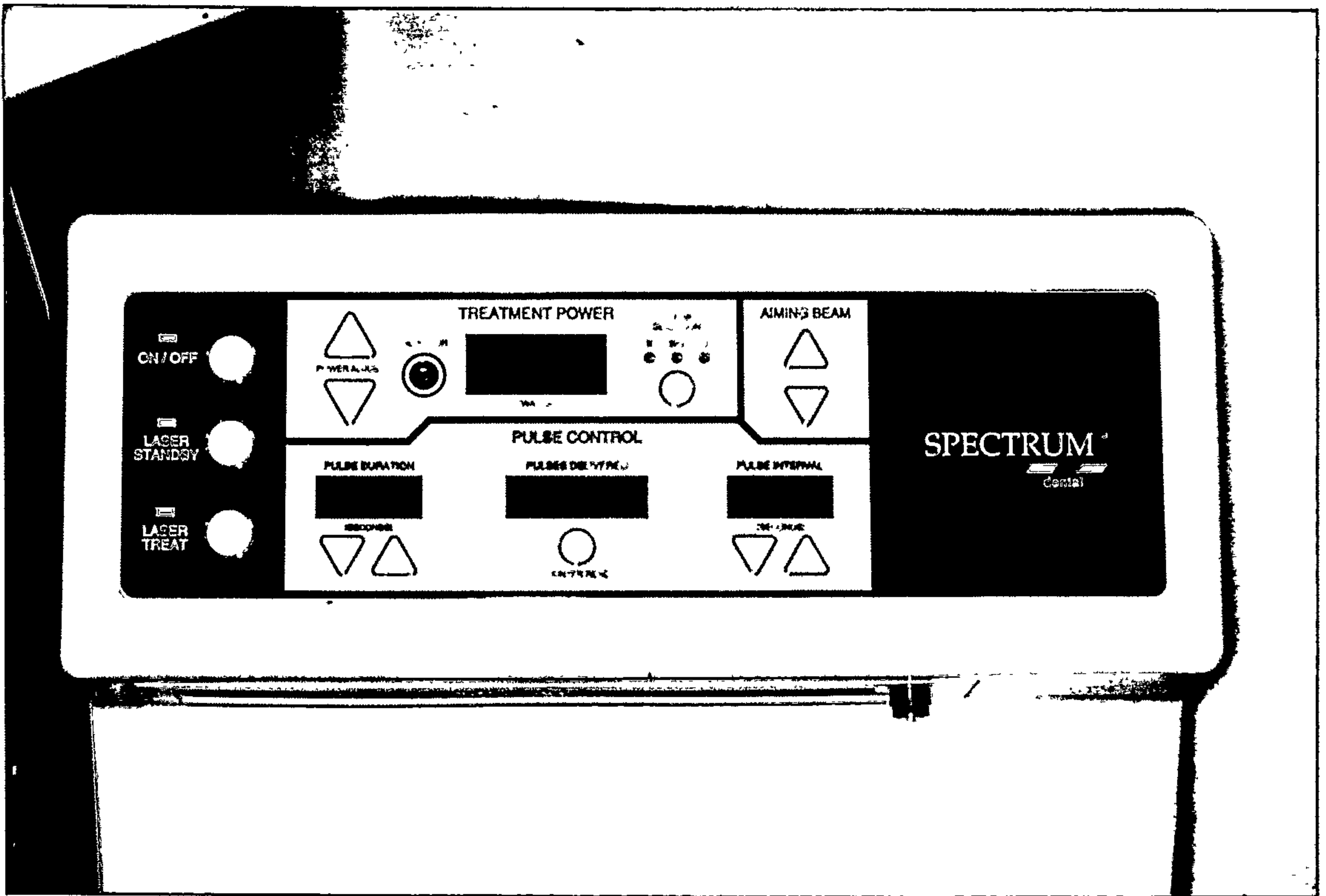
Table 5.a. The mean pulpal temperature rise (with standard deviation) bluelines versus blue-green multilines argon laser, at 5sec intervals, with mean tooth thickness of 2.8±0.2mm.

Spot size	1mm	2mm	3mm	4mm	5mm
B-5sec	1.7±0.2°C	1.6±0.2°C	1.4±0.2°C	1.3±0.2°C	1.2±0.2°C
B-10sec	3.7±0.5°C	3.4±0.5°C	3.0±0.5°C	2.8±0.4°C	2.5±0.4°C
B-15sec	5.5±0.7°C	5.1±0.6°C	4.6±0.6°C	4.1±0.4°C	3.7±0.4°C
B-20sec	6.8±0.8°C	6.2±0.7°C	5.7±0.6°C	5.1±0.4°C	4.5±0.4°C
BG-5sec	1.6±0.3°C	1.3±0.2°C	1.3±0.2°C	1.2±0.2°C	1.1±0.2°C
BG-10sec	3.4±0.4°C	3.0±0.3°C	2.7±0.3°C	2.6±0.3°C	2.2±0.4°C
BG-15sec	4.9±0.7°C	4.4±0.5°C	4.0±0.4°C	3.7±0.3°C	3.2±0.4°C
BG-20sec	6.0±0.8°C	5.4±0.6°C	4.8±0.5°C	4.5±0.4°C	3.9±0.3°C

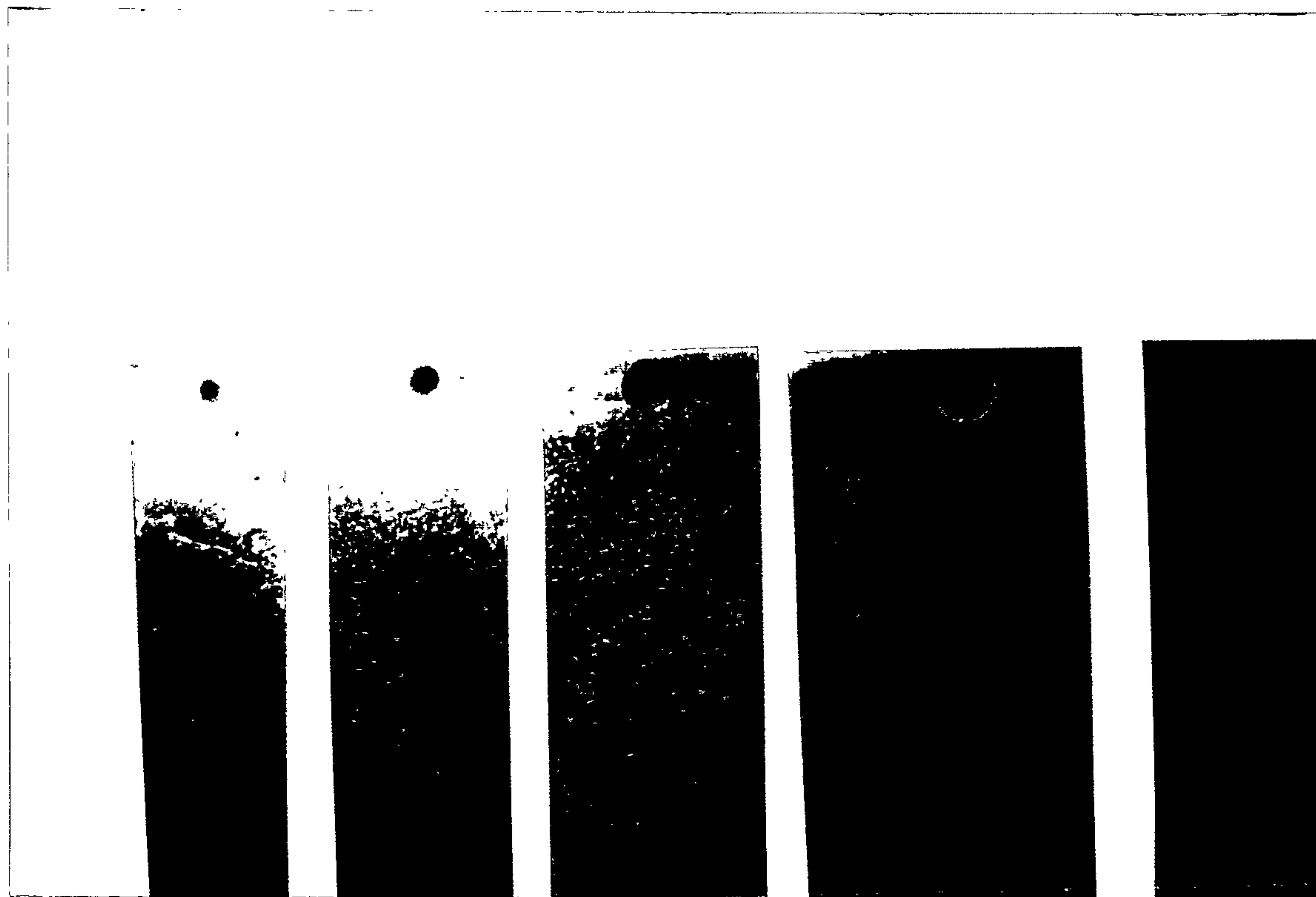
B=Blueline, BG=Bluegreen multilines.



P5-1. This photograph illustrates the test tooth in a 37 °C water bath.
A rigid positioning jig is being used to secure the laser handpiece.



P5-2. This photograph illustrates an argon laser, HGM¹⁰
(Dental Spectrum 400).



P5-3. Templates of different spot sizes (range : 1-5mm diameter) to set the distance between the fibre and the irradiated tooth surface.

Fig. 5.a. Mean Temperature Change vs Spot Size
Blue Singleline Argon Laser

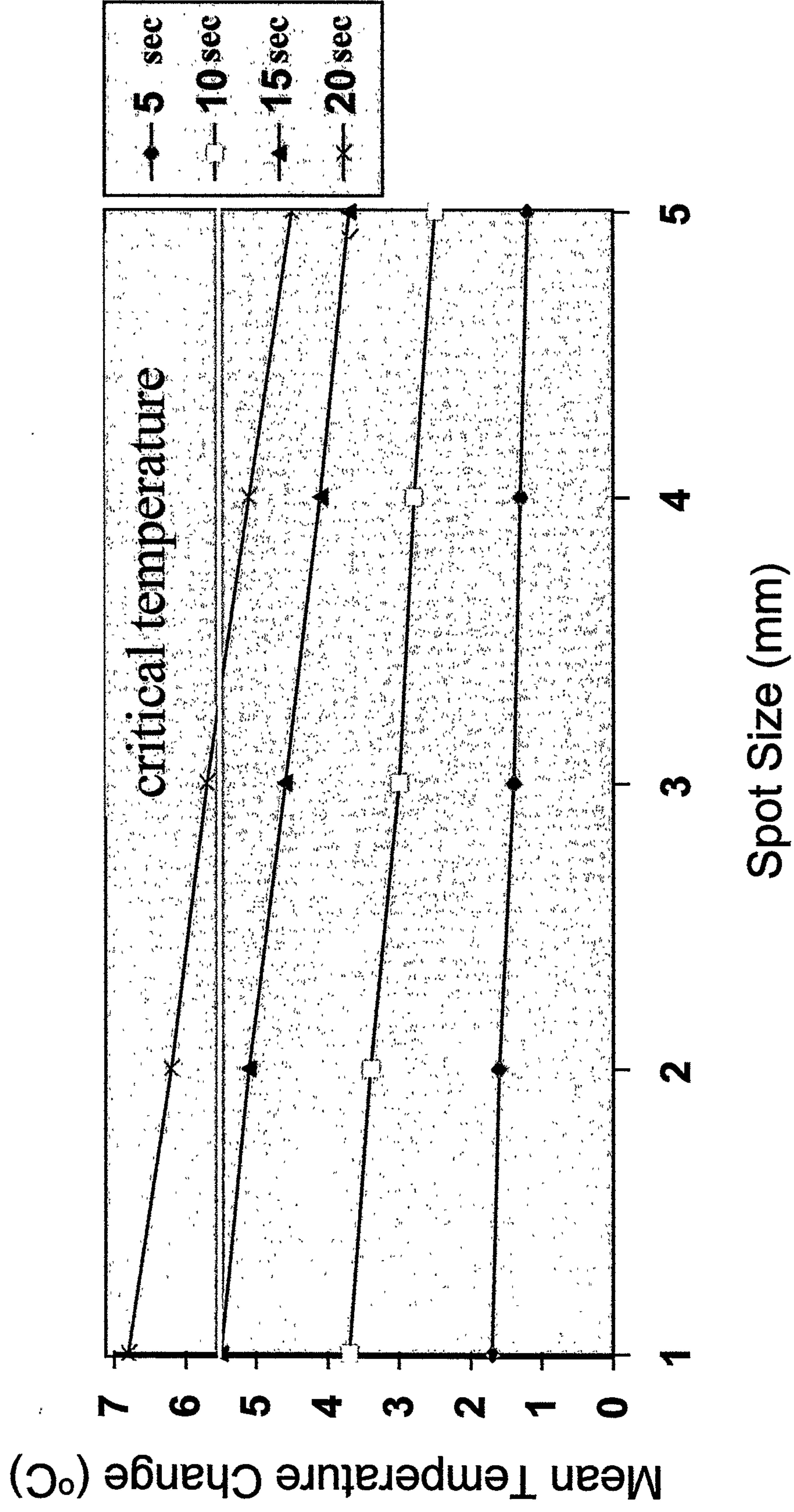
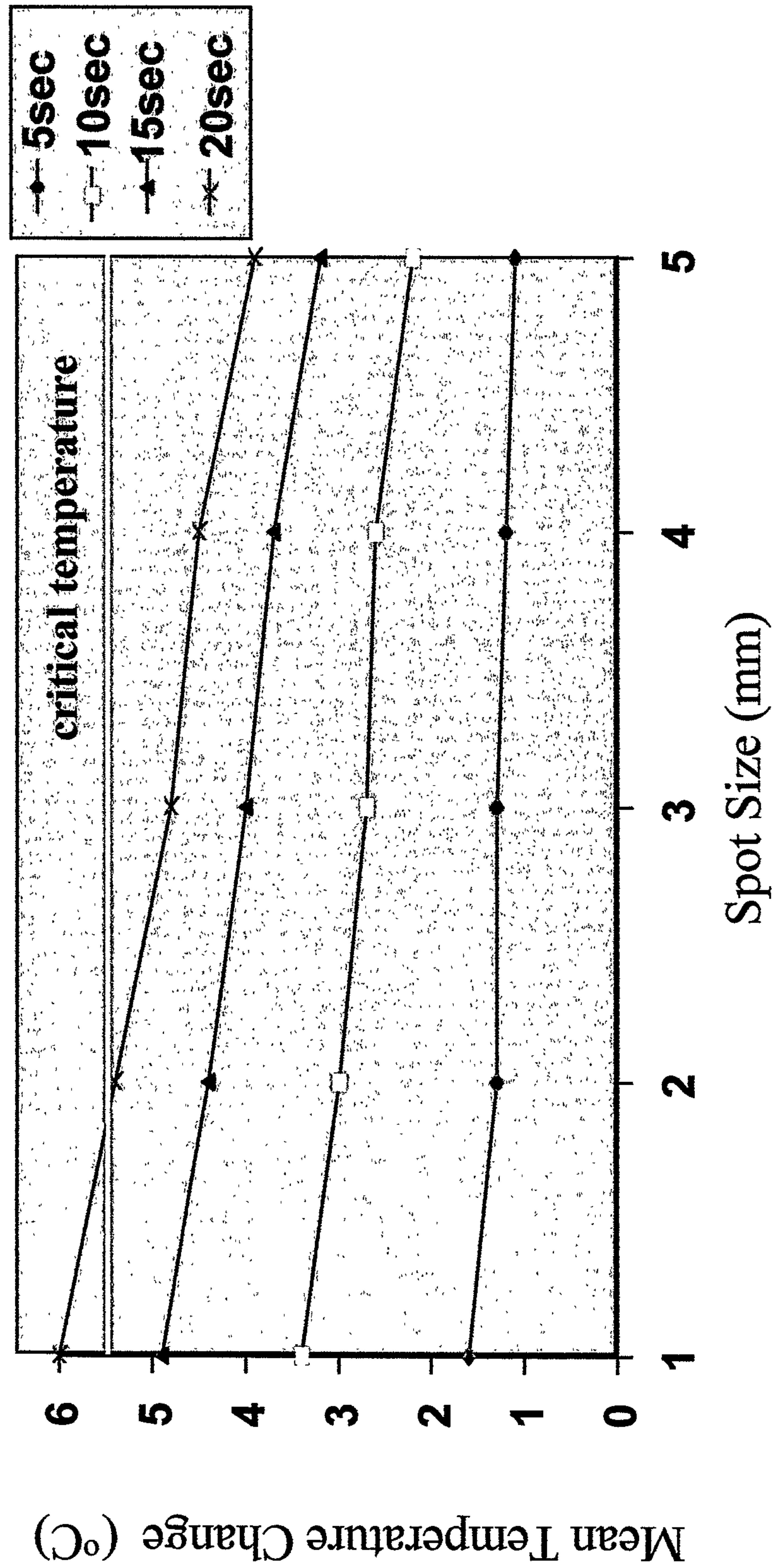


Fig. 5.b. Mean Temperature Change vs Spot Size
Bluegreen Multiline Argon Laser



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Appendix I.a. EMLA group- the complete data (experiment:1).

Patient no.	Age/ Sex	Agent	Tooth	Cavity (C/IC)	Pre-EPT	Post-EPT	EPT difference	Pain score (mm)
1	15 /M	E	35	IC	46	50	+4	17
2	14 /M	E	34	IC	50	75	+25	46
3	14/ F	E	14	C	57	65	+8	3
4	17/ F	E	24	C	36	42	+6	43
5	16/ M	E	45	IC	43	68	+25	21
6	14/ M	E	24	C	48	68	+20	1
7	16/ F	E	14	C	34	40	+6	18
8	14/ F	E	24	IC	16	32	+16	2
9	14/ F	E	25	C	26	53	+ 7	13
10	15/ F	E	14	C	42	46	+ 4	1
11	14/ M	E	14	IC	56	50	- 6	19
12	17/ F	E	14	C	49	64	+15	5
13	14/ F	E	45	C	70	72	+ 2	45
14	14/ M	E	25	C	74	80	+ 6	36
15	16/ M	E	24	C	36	37	+ 1	45
16	14/ F	E	35	C	54	66	+12	24
17	16/ F	E	25	IC	33	36	+ 3	1
18	16/ M	E	25	C	58	54	- 4	18
19	16/ M	E	14	IC	63	47	-16	15
20	16/ M	E	15	IC	38	48	+10	44
21	14/ F	E	15	IC	42	77	+35	16
22	16/ F	E	25	C	62	80	+18	46
23	14/ F	E	24	C	44	30	-14	7
24	16/ M	E	24	C	34	64	+30	18
25	14/ F	E	25	C	36	65	+31	50
26	17/ F	E	24	C	65	69	+ 4	21
27	15/ M	E	25	C	65	80	+15	82
28	16/ M	E	24	C	67	48	-19	6
29	16/ F	E	14	C	41	71	+30	6
30	15/ M	E	14	C	28	39	+11	22
31	17/ M	E	15	IC	51	44	- 7	13
32	15/ F	E	24	C	34	80	+46	16
33	18/ M	E	24	C	24	80	+56	8
34	14/ F	E	35	IC	57	61	+ 4	21
35	15/ M	E	45	C	63	80	+17	59
36	14/ F	E	35	IC	40	80	+40	4
37	14/ M	E	45	C	53	80	+27	21
38	14/ M	E	35	IC	62	80	+18	23
39	17/ F	E	35	IC	47	57	+10	37
40	16/ M	E	44	IC	40	30	-10	37
41	15/ M	E	35	C	62	56	- 6	37
42	16/ F	E	34	IC	53	68	+15	11
43	18/ M	E	45	IC	58	80	+22	29
44	15/ F	E	35	IC	60	61	+ 1	2

EPT= Electical Pulp Testing, C= Complete standardised cavity,
IC = Incompleted standardised cavity, E= EMLA 5% anaesthetic cream,
M =Male, F= Female.

Appendix I.b. Laser group- the complete data (experiment:1).

Patient no.	Age/ Sex	Power (W)	Agent	Tooth	Cavity (C/IC)	Pre-EPT	Post-EPT	EPT difference	Pain score (mm)
1	15 /M	1.05	L	45	C	48	60	+12	20
2	14 /M	1.05	L	44	IC	66	80	+14	61
3	14/ F	1.05	L	24	C	40	59	+19	3
4	17/ F	1.05	L	14	C	58	69	+11	53
5	16/ M	1.05	L	35	IC	17	58	+41	25
6	14/ M	0.88	L	14	C	48	53	+ 5	4
7	16/ F	0.88	L	24	C	35	38	+ 3	10
8	14/ F	0.88	L	14	C	27	32	+ 5	1
9	14/ F	0.88	L	15	C	68	70	+ 2	26
10	15/ F	0.93	L	24	C	51	51	0	1
11	14/ M	0.95	L	24	IC	53	36	-17	14
12	17/ F	1.30	L	24	C	45	52	+ 7	5
13	14/ F	1.30	L	35	C	59	54	- 5	75
14	14/ M	1.30	L	15	C	76	80	+ 4	22
15	16/ M	1.25	L	14	IC	59	49	-10	56
16	14/ F	1.00	L	45	IC	70	62	- 8	13
17	16/ F	1.25	L	15	IC	39	49	+10	9
18	16/ M	1.20	L	15	IC	42	49	+ 7	19
19	16/ M	1.15	L	24	IC	29	23	- 6	14
20	16/ M	1.15	L	25	C	48	47	- 1	43
21	14/ F	1.20	L	25	C	55	59	+ 4	16
22	16/ F	1.20	L	15	IC	80	80	0	10
23	14/ F	1.25	L	14	IC	46	51	+ 5	8
24	16/ M	1.30	L	14	C	42	57	+15	5
25	14/ F	1.30	L	15	C	53	63	+10	45
26	17/ F	1.25	L	15	C	41	47	+ 6	25
27	15/ M	1.25	L	15	C	68	80	+14	68
28	16/ M	1.15	L	14	IC*	56	59	+ 3	14
29	16/ F	1.20	L	24	C	46	59	+13	2
30	15/ M	1.20	L	24	C	48	80	+32	39
31	17/ M	1.20	L	25	C	26	53	+27	16
32	15/ F	1.20	L	14	C	27	50	+23	2
33	18/ M	1.00	L	14	C	39	42	+ 3	21
34	14/ F	1.30	L	45	C	39	53	+14	4
35	15/ M	0.90	L	35	C	48	80	+32	59
36	14/ F	1.10	L	45	C	61	80	+19	1
37	14/ M	1.10	L	35	C	54	75	+21	6
38	14/ M	1.20	L	45	C	69	80	+11	9
39	17/ F	1.15	L	45	IC	27	61	+34	7
40	16/ M	1.15	L	34	C	38	69	+11	53
41	15/ M	1.10	L	45	C	51	57	+ 6	37
42	16/ F	1.10	L	44	C	41	80	+39	3
43	18/ M	1.05	L	35	IC	56	57	+ 1	38
44	15/ F	1.20	L	45	IC	59	69	+10	0

EPT= Electical Pulp Testing, C= Complete standardised cavity,
IC = Incomplected standardised cavity, L= Pulsed Nd:YAG laser,
M=Male, F= Female, (*)= Tooth became hyperalgesic after lasing.

Appendix IIa. Study 3- the complete experimental data.

Power (W)	Freq. (Hz)	Tooth no.	B- thick ness (mm)	L- thick ness (mm)	B- tmax (secs)	L- tmax (secs)	B- Tmax (°C)	L- Tmax (°C)	L- tretur n(secs)	b- tretur n(secs)
0.35	10	1	3.0	2.5	43	36	2.0	1.8	30	30
0.35	10	2	3.1	2.5	36	50	1.8	1.8	25	25
0.35	10	3	3.1	2.5	32	34	1.6	1.4	24	24
0.35	10	4	2.9	2.5	37	34	1.4	1.4	25	25
0.35	10	5	3.0	3.0	46	35	1.6	1.4	35	35
0.35	10	6	3.0	3.0	32	30	1.5	1.2	27	27
0.35	10	7	3.0	2.8	50	43	2.0	1.8	55	71
0.35	10	8	2.8	2.8	40	39	1.9	1.9	55	70
0.35	10	9	3.0	3.0	34	35	1.4	1.3	25	25
0.35	10	10	3.0	3.0	52	50	1.7	1.5	38	47
0.50	10	11	3.2	3.0	52	57	2.2	2.2	65	90
0.50	10	12	3.2	3.0	46	42	2.4	2.3	57	87
0.50	10	13	3.0	3.0	55	52	2.0	2.0	56	75
0.50	10	14	2.8	2.8	48	48	1.8	1.6	60	70
0.50	10	15	3.0	3.0	42	42	2.4	2.0	55	65
0.50	10	16	2.9	2.9	37	42	2.6	2.4	56	75
0.50	10	17	2.9	2.5	57	57	2.3	2.2	55	70
0.50	10	18	3.0	2.5	41	45	2.6	2.2	57	78
0.50	10	19	2.5	2.3	42	40	2.8	2.0	59	59
0.50	10	20	2.5	2.5	42	42	2.8	2.4	55	70
0.75	10	21	3.0	2.9	60	52	4.0	3.8	70	105
0.75	10	22	3.0	3.0	58	56	4.0	3.8	68	110
0.75	10	23	3.1	3.0	56	51	3.6	3.4	68	100
0.75	10	24	2.9	2.9	52	45	3.6	3.4	67	90
0.75	10	25	3.5	3.1	80	75	4.2	4.0	65	90
0.75	10	26	3.5	3.0	78	73	4.5	4.2	63	86
0.75	10	27	3.0	2.8	43	40	3.4	3.2	65	100
0.75	10	28	3.2	3.0	51	44	3.4	3.1	70	95
0.75	10	29	3.0	2.8	45	40	3.4	3.2	60	95
0.75	10	30	3.0	2.8	55	50	3.5	3.3	56	90
0.30	15	31	3.0	3.5	52	32	2.4	1.6	48	58
0.30	15	32	3.0	3.5	54	50	2.2	2.0	46	65
0.30	15	33	3.5	3.0	55	55	2.0	2.0	60	60
0.30	15	34	3.5	3.0	53	45	2.0	1.8	59	65
0.30	15	35	3.0	2.0	36	32	2.2	1.8	40	55
0.30	15	36	3.0	2.0	39	36	2.2	1.8	50	60
0.30	15	37	3.0	3.0	38	38	2.0	2.0	38	60
0.30	15	38	3.0	3.0	38	34	1.8	1.8	40	51
0.30	15	39	2.0	3.0	54	50	2.0	1.8	55	65
0.30	15	40	2.0	3.0	51	48	2.2	2.0	58	65

B-thickness= Buccal thermocouples, tooth thickness ,
B-tmax= Buccal thermocouples, time to reach the maximum temperature,
B-Tmax= Buccal thermocouples, the maximum temperature,
B-treturn = Buccal thermocouples, the recovery time frommaximum temperature to baseline.
L-thickness= Lingual thermocouples, tooth thickness ,
L-tmax= Lingual thermocouples, time to reach the maximum temperature,
L-Tmax= Lingual thermocouples, the maximum temperature,
L-treturn = Lingual thermocouples, the recovery time frommaximum temperature to baseline.

Power (W)	Freq. (Hz)	Tooth no.	B- thick ness (mm)	L- thick ness (mm)	B- tmax (secs)	L- tmax (secs)	B- Tmax (°C)	L- Tmax (°C)	L- tretur n(secs)	b- tretur n(secs)
0.65	15	41	3.0	3.0	64	48	4.6	3.6	75	75
0.65	15	42	3.0	3.0	63	50	4.6	3.8	80	85
0.65	15	43	2.0	2.0	65	50	4.7	3.6	65	70
0.65	15	44	2.0	2.0	60	52	4.6	3.6	75	75
0.65	15	45	3.0	3.0	72	60	4.6	4.0	62	62
0.65	15	46	3.0	3.0	75	65	4.3	4.0	76	76
0.65	15	47	3.0	3.0	50	46	4.2	3.6	76	76
0.65	15	48	3.0	3.0	55	50	4.8	4.0	82	82
0.65	15	49	3.0	3.0	72	65	3.6	3.5	63	65
0.65	15	50	3.0	3.0	68	65	3.6	3.5	65	65
0.95	15	51	3.0	2.5	80	52	6.6	4.6	75	85
0.95	15	52	3.0	2.5	78	50	6.4	4.5	75	90
0.95	15	53	3.0	2.8	83	80	6.6	6.4	80	85
0.95	15	54	3.0	2.8	76	74	6.7	6.4	90	95
0.95	15	55	3.0	3.0	55	48	6.5	5.0	80	95
0.95	15	56	3.0	3.0	45	40	6.5	4.8	73	100
0.95	15	57	3.0	3.5	85	80	6.8	6.6	85	95
0.95	15	58	3.0	3.5	79	70	6.6	6.5	83	94
0.95	15	59	3.0	3.0	60	50	5.7	5.0	80	100
0.95	15	60	3.0	3.0	50	43	5.0	4.8	75	90
1.50	15	61	2.8	2.5	75	70	6.8	8.5	76	105
1.50	15	62	2.8	2.5	69	60	8.8	8.0	76	100
1.50	15	63	2.8	2.5	89	72	8.7	8.4	70	130
1.50	15	64	2.8	2.5	75	62	8.8	8.0	78	135
1.50	15	65	3.0	2.8	78	52	9.6	6.2	87	110
1.50	15	66	3.0	2.8	71	50	10.0	6.2	87	120
1.50	15	67	2.8	3.0	84	58	9.4	6.8	85	93
1.50	15	68	2.8	3.0	60	56	10.6	6.8	75	90
1.50	15	69	3.0	3.0	61	46	9.4	7.2	95	100
1.50	15	70	3.0	3.0	62	44	9.3	7.0	94	110
0.30	20	71	3.0	2.5	58	56	2.0	2.0	40	40
0.30	20	72	3.0	2.5	65	57	2.2	2.0	35	35
0.30	20	73	3.0	2.5	60	50	2.8	2.0	54	54
0.30	20	74	3.0	2.5	40	37	2.2	2.0	40	40
0.30	20	75	3.0	3.0	58	50	2.5	2.0	55	70
0.30	20	76	3.0	3.0	71	58	2.6	2.0	50	70
0.30	20	77	3.0	2.8	76	63	3.4	3.0	70	75
0.30	20	78	3.0	2.8	65	60	3.2	3.0	65	70
0.30	20	79	3.0	3.0	50	40	2.2	1.8	40	40
0.30	20	80	3.0	3.0	65	52	2.5	1.6	40	50

B-thickness= Buccal thermocouples, tooth thickness ,
B-tmax= Buccal thermocouples, time to reach the maximum temperature,
B-Tmax= Buccal thermocouples, the maximum temperature,
B-treturn = Buccal thermocouples, the recovery time frommaximum temperature to baseline.
L-thickness= Lingual thermocouples, tooth thickness ,
L-tmax= Lingual thermocouples, time to reach the maximum temperature,
L-Tmax= Lingual thermocouples, the maximum temperature,
L-treturn = Lingual thermocouples, the recovery time frommaximum temperature to baseline.

Power (W)	Freq. (Hz)	Tooth no.	B-thick ness (mm)	L-thick ness (mm)	B-tmax (secs)	L-tmax (secs)	B-Tmax (°C)	L-Tmax (°C)	L-tretur n(secs)	b-tretur n(secs)
0.50	20	81	3.2	3.0	78	67	5.0	4.2	57	85
0.50	20	82	3.2	3.0	58	46	5.0	3.6	70	86
0.50	20	83	2.5	3.0	77	48	4.7	2.0	40	50
0.50	20	84	2.5	3.0	70	45	4.6	2.0	57	80
0.50	20	85	3.0	2.5	65	50	3.2	2.4	65	70
0.50	20	86	3.0	2.5	63	52	3.4	2.0	70	75
0.50	20	87	3.0	3.0	67	50	3.0	2.4	55	55
0.50	20	88	3.0	3.0	43	40	3.0	2.0	60	60
0.50	20	89	3.0	3.0	47	40	3.0	2.0	48	75
0.50	20	90	3.0	3.0	77	65	4.4	2.3	57	67
0.95	20	91	3.0	3.0	84	70	8.4	7.0	80	100
0.95	20	92	3.0	3.0	85	48	8.4	5.8	70	95
0.95	20	93	3.5	3.0	64	57	7.2	6.8	70	115
0.95	20	94	3.5	3.0	63	55	7.2	6.8	70	92
0.95	20	95	3.0	3.0	78	60	7.8	6.8	110	110
0.95	20	96	3.0	3.0	74	65	7.6	6.5	100	100
0.95	20	97	3.0	3.0	78	62	7.4	6.2	95	120
0.95	20	98	3.0	3.0	80	70	7.4	6.2	90	120
0.95	20	99	3.0	3.5	74	72	7.8	7.5	125	125
0.95	20	100	3.0	3.5	68	65	7.8	7.5	120	120
1.15	20	101	3.0	3.5	65	63	9.2	9.0	115	115
1.15	20	102	3.0	3.5	75	73	9.0	9.0	136	136
1.15	20	103	3.0	3.0	86	60	10.6	5.8	120	125
1.15	20	104	3.0	3.0	82	62	10.8	5.8	95	118
1.15	20	105	3.0	3.0	70	62	8.6	7.0	87	100
1.15	20	106	3.0	3.0	79	68	8.4	6.2	80	95
1.15	20	107	3.0	2.0	69	68	8.2	8.2	120	120
1.15	20	108	3.0	2.0	58	50	8.2	6.8	95	125
1.15	20	109	2.5	2.5	100	79	12.0	8.4	105	145
1.15	20	110	2.5	2.5	90	70	9.6	8.4	105	134

Appendix IIb. Statistic analysis-Spearman’s Rho Correlation between power and frequency (P<0.05).

p-values	B-tmax	L-tmax	B-Tmax	L-Tmax	L-treturn	B-treturn
10Hz	0.000	0.002	0.000	0.000	0.000	0.000
15Hz	0.000	0.006	0.000	0.000	0.000	0.000
20Hz	0.001	0.001	0.000	0.000	0.000	0.000

B-thickness= Buccal thermocouples, tooth thickness ,
B-tmax= Buccal thermocouples, time to reach the maximum temperature,
B-Tmax= Buccal thermocouples, the maximum temperature,
B-treturn = Buccal thermocouples, the recovery time frommaximum temperature to baseline.
L-thickness= Lingual thermocouples, tooth thickness ,
L-tmax= Lingual thermocouples, time to reach the maximum temperature,
L-Tmax= Lingual thermocouples, the maximum temperature,
L-treturn = Lingual thermocouples, the recovery time from the maximum temperature to baseline.

Appendix IIIa. Study 4- the complete experimental data.

Tooth no.	Thermo-couples	Agent	Thick-ness (mm)	10secs (°C)	20secs (°C)	30secs (°C)	40secs (°C)	50secs (°C)	60secs (°C)	Recover-y time (secs)
1	BC	Nd	2.0	2	3.5	5	6	7	8.5	110
1	BC	Er	2.0	0	3.5	3.5	4.5	3.5	2.5	2
1	LC	Nd	2.0	1	1.5	4.5	6.5	7.5	8.5	120
1	LC	Er	2.0	0	4	2	2.5	2.5	2	2*
2	BC	Nd	2.3	2	4	5.5	6.5	8	9	70
2	BC	Er	2.3	1	1	1	1	1	1	2
2	LC	Nd	2.3	2.5	4.5	5.5	6.5	6.5	6.5	90
2	LC	Er	2.3	0	0	0.5	0.5	0.5	0.5	2
3	BC	Nd	2.2	2	5	6	7	7.5	8	110
3	BC	Er	2.2	0.5	2	1.5	1	1	0.5	3
3	LC	Nd	2.2	6	7	8.5	9.5	10	10	60
3	LC	Er	2.2	0	3.5	4.5	4.5	4.5	4	5
4	BC	Nd	2.5	2	2.5	2.5	2.5	2.5	2.5	20
4	BC	Er	2.5	1	2	2	2	3	2	3
4	LC	Nd	2.5	1.5	3	4	5	5.5	5.5	70
4	LC	Er	2.5	1	2.5	1.5	1.5	1.5	1.5	2
5	BC	Nd	2.0	3	6	8	9	10.5	11.5	110
5	BC	Hs	2.0	-1	0	2	4	5.5	5.5	30
5	LC	Nd	2.0	5.5	7.5	9	10	11	11.5	120
5	LC	Er	2.0	0.5	2	2.5	2.5	2	1	2.5
6	BC	Nd	2.0	3	5	6.5	7.5	8.5	9	120
6	BC	Hs	2.0	-1.5	2	5	5	4	4.5	50
6	LC	Nd	2.0	4	7	8.5	10	10.5	11.5	120
6	LC	Er	2.0	0	1.5	1.5	1.5	1	0	0
7	BC	Nd	2.0	3	6.5	8	9.5	10.5	11	120
7	BC	Er	2.0	1.5	4	3.5	3	2	2	5
7	LC	Nd	2.0	4	5	6	6.5	7.5	8.5	80
7	LC	Er	2.0	1	2	2	3	2.5	*	
8	BC	Nd	2.3	5.5	7	8	8.5	9	9.5	80
8	BC	Hs	2.3	-0.5	0	2	2.5	2	2.5	40
8	LC	Nd	2.3	3.5	5	6	6	6.5	6.5	70
8	LC	Er	2.3	0	0.5	1	1.5	2.5	3	1
9	BC	Nd	2.3	3	4.5	5.5	6	6.5	7	90
9	BC	Hs	2.3	-1	3	3.5	3	2.5	2.5	40
9	LC	Nd	2.3	1.5	2	2	2	2	2.5	80
9	LC	Er	2.3	0	1	2	1	2	0.5	5
10	BC	Nd	2.5	1	1.5	2	2.5	2.5	2.5	50
10	BC	Hs	2.5	-0.5	0.5	1.5	1.5	3	3	30
10	LC	Nd	2.5	2	3	3.5	3.5	3.5	3.5	80
10	LC	Er	2.5	1	3	2	0.5	0.5	1	1
11	BC	Nd	2.3	2	5	7	8	9	10	70
11	BC	Er	2.3	0	0.5	1	2	2	*	
11	LC	Nd	2.3	2	3.5	5	6	7	8	50
11	LC	Er	2.3	2	0.5	0	1.5	1.5	1.5	5

12	BC	Nd	2.0	1	5	6.5	7.5	8.5	9	50
12	BC	Er	2.0	0.5	3	2	0.5	0.5	0.5	2*
12	LC	Nd	2.0	3	4.5	5	5.5	6	6	30
12	LC	Er	2.0	0	2	2	2	3	*	
13	BC	Nd	2.5	3	5	6	6.5	7	7.5	60
13	BC	Er	2.5	0	1.5	1.5	1	1	0.5	2
13	LC	Nd	2.55	3.5	5.5	8.5	9.5	10.5	11.5	120
13	LC	Hs	2.55	-2	0	4	4	3.5	3.5	30

BC=buccal thermocouples, LC= lingual/palatal thermocouples, Nd= pulsed Nd:YAG laser, Er= pulsed Er:YAG laser, Hs= Highspeed drill, *= reached the thermocouples.

Appendix IIIb. Statistic analysis-paired t-test (P<0.05) and F-distribution sample variance.

Time	Nd versus Er	Nd versus Hs	Er versus Hs	F-variance
10 sec	0.000	0.001	0.308	1.086
20 sec	0.000	0.011	0.746	0.108
30 sec	0.000	0.017	0.193	1.791
40 sec	0.000	0.005	0.789	0.073
50 sec	0.000	0.010	0.853	0.035
60 sec	0.000	0.010	0.741	0.112
Recovery time	0.000	0.003	0.000	34.868

Nd= pulsed Nd:YAG laser, Er= pulsed Er:YAG laser, Hs= Highspeed drill.

Appendix IVa. Study 5.- the complete experimental data.

Tooth no.	Spot size (mm)	B- 5secs	B- 10secs	B- 15secs	B- 20secs	BG- 5secs	BG- 10secs	BG- 15secs	BG- 20secs
1	1	1.8	3.8	5.8	7.1	1.4	3.3	5.2	6.6
2	1	1.8	3.8	5.5	7.0	1.5	3.6	5.2	6.5
3	1	1.7	3.5	5.0	6.1	2.0	3.5	4.8	6.0
4	1	1.7	3.5	5.0	6.1	2.0	3.6	5.0	6.0
5	1	1.9	3	4.7	6.6	1.7	2.8	4.3	5.5
6	1	1.9	3.5	5.2	6.8	1.5	2.9	4.4	5.5
7	1	1.9	4.4	6.1	7.2	2.0	4.1	5.5	6.3
8	1	1.9	4.1	6.3	7.2	1.9	4.0	5.5	6.1
9	1	1.9	4.4	6.7	7.7	1.8	4.0	5.5	6.9
10	1	2.0	4.6	6.6	7.5	1.8	3.9	6.0	6.9
11	1	1.5	3.9	6.1	8.4	1.5	3.3	6.1	7.5
12	1	1.6	4.6	6.8	8.4	1.5	3.6	6.0	7.6
13	1	1.4	3.3	5.1	6.4	1.5	3.1	5.0	5.6
14	1	1.4	3.1	5.0	6.4	1.2	3.1	4.6	5.7
15	1	1.3	3.2	4.5	5.6	1.5	3.0	4.1	4.9
16	1	1.9	3.7	4.9	5.8	1.5	3.2	4.0	4.8
17	1	1.6	3.9	5.9	7.1	1.3	3.4	4.9	6.0
18	1	1.8	3.8	5.8	7.3	1.2	3.1	4.7	5.9
19	1	1.6	3.2	4.6	5.6	1.5	2.8	3.9	5.0
20	1	1.8	3.3	4.9	6.1	1.5	3.0	4.0	5.0
21	2	1.5	3.3	5	6.6	1.2	2.7	4.4	5.7
22	2	1.3	3	5	6.5	1.1	2.6	4.3	5.8
23	2	1.4	2.9	4.4	5.4	1.1	2.5	3.7	4.6
24	2	1.3	2.8	4.3	5.3	1.2	2.7	4	4.8
25	2	1.7	3.5	4.8	5.9	1.3	2.8	4.1	5.2
26	2	1.8	3.3	5.3	6.1	1.3	2.8	4.3	5.1
27	2	1.8	3.9	5.3	5.7	1.7	3.3	4.2	4.7
28	2	1.8	3.8	5.2	5.4	1.5	3.4	4.2	4.8
29	2	1.7	4.3	6	6.9	1.1	2.9	4.6	6.2
30	2	1.8	3.6	5.8	6.9	1.4	3.3	4.8	6.2
31	2	2	4.5	6.3	7.5	1.4	3.6	5.5	6.7
32	2	1.6	3.6	6.1	7.5	1.4	3.6	5.5	6.7
33	2	1.1	3	5	6.2	1.4	3.2	4.8	5.5
34	2	1.2	3	4.7	6.1	1.2	3	4.5	5.4
35	2	1.7	3.3	4.6	5.6	1.5	3	4	5.2
36	2	1.7	3.6	4.9	5.8	1.5	3.1	4	4.8
37	2	1.6	3.6	5.2	6.6	1.3	3.3	4.4	5.4
38	2	1.8	4.1	5.8	7	1.2	3.1	4.7	5.7
39	2	1.3	2.7	4.1	5.4	1.4	2.6	4	5.1
40	2	1.4	3	4.3	5.5	1.3	2.6	4	5

B=Blue singliline argon laser, BG= Bluegreen multilines argon laser.

Tooth no.	Spot size (mm)	B- 5secs	B- 10secs	B- 15secs	B- 20secs	BG- 5secs	BG- 10secs	BG- 15secs	BG- 20secs
41	3	1.3	2.9	4.4	5.4	1.4	2.6	3.9	4.6
42	3	1.3	2.7	4.2	5.3	1.3	2.6	3.9	4.7
43	3	1.4	2.9	4.1	5.2	1.4	2.6	3.8	4.7
44	3	1.4	2.9	4.1	5.2	1.4	2.6	3.9	4.7
45	3	1.3	2.7	4.1	5.5	1.3	2.6	3.8	4.8
46	3	1.4	2.8	4.3	5.6	1.2	2.8	3.9	4.7
47	3	1.4	2.6	4.2	4.8	1.1	2.4	3.5	4.2
48	3	1.3	2.7	4.2	5.1	1.1	2.5	3.5	4
49	3	1.3	3.3	5	6.5	1.4	2.6	4.3	5.5
50	3	1.4	2.5	5.4	6.5	1.4	2.8	4.4	5.1
51	3	1.4	3.4	5.4	6.8	1.4	3.5	5	5.8
52	3	1.6	3.6	5.4	6.8	1.3	3.4	4.8	5.8
53	3	1.1	2.7	4	5.1	1.1	2.4	3.6	4.5
54	3	1.3	2.7	3.8	5.3	1	2.2	3.5	4.5
55	3	1.3	3.1	4.6	5.5	1.5	2.8	4	4.8
56	3	1.5	3.5	4.8	5.7	1.5	2.8	3.8	4.8
57	3	1.8	3.9	5.5	6.2	1.5	3.1	4.3	5.1
58	3	1.8	4.1	5.8	6.6	1.5	3.1	4.2	5
59	3	1.3	2.5	4	5	1.5	2.6	3.7	4.5
60	3	1.4	2.9	4.1	5.2	1.4	2.4	3.8	4.5
61	4	1.2	2.5	3.8	4.9	1.1	2.2	3.5	4.3
62	4	1.2	2.5	3.9	4.9	1.1	2.3	3.5	4.4
63	4	1.3	2.6	3.6	4.6	1.3	2.5	3.5	4.4
64	4	1.3	2.5	3.6	4.6	1.2	2.5	3.5	4.5
65	4	1.1	2.5	3.7	5	1	2.3	3.5	4.3
66	4	1.3	2.9	4.1	5.1	1	2.3	3.5	4.4
67	4	1.3	2.5	3.8	4.8	1.1	2.4	3.4	4
68	4	1.3	2.5	3.8	4.9	1.1	2.4	3.5	4.2
69	4	1.5	3.2	4.5	5.7	1.3	3	4.1	4.9
70	4	1.3	2.9	4.6	5.6	1.3	3	4	4.8
71	4	1.5	3.4	4.7	6.1	1.4	3.2	4.4	5.2
72	4	1.5	3.5	4.9	5.8	1.7	3.3	4.4	5.3
73	4	1.0	2.3	3.6	4.3	1.0	2.7	3.8	4.8
74	4	1.2	2.7	3.8	4.9	0.9	2.1	3.5	4.3
75	4	1.2	2.6	3.6	4.6	1.3	2.4	3.4	4.3
76	4	1.3	2.6	3.7	4.6	1.3	2.6	3.4	4.3
77	4	1.7	3.3	4.3	4.9	1.3	2.6	3.6	4
78	4	1.7	3.5	4.6	5.2	1.4	2.8	3.7	4.3
79	4	1.2	2.4	3.9	4.8	1.1	2.4	3.5	4.5
80	4	1.5	2.8	4.3	5.3	1	2.3	3.6	4.5

B=Blue singliline argon laser, BG= Bluegreen multilines argon laser.

Tooth no.	Spot size (mm)	B- 5secs	B- 10secs	B- 15secs	B- 20secs	BG- 5secs	BG- 10secs	BG- 15secs	BG- 20secs
81	5	1.1	2.5	3.7	4.6	1.0	2.1	3.1	3.8
82	5	1.2	2.6	3.9	4.8	1.0	2.1	3.1	4.0
83	5	1.2	2.6	3.6	4.3	1.1	2.2	3.2	3.8
84	5	1.2	2.6	3.6	4.3	1.1	2.2	3.2	3.8
85	5	1.0	2.1	3.3	4.1	0.9	1.9	2.8	3.4
86	5	0.9	2.3	3.3	4.2	0.9	1.9	2.8	3.5
87	5	0.9	2.0	3.3	4.1	0.9	1.8	2.8	3.6
88	5	1.0	2.0	3.1	4.2	0.9	1.8	2.7	3.5
89	5	1.2	2.6	3.7	5.0	1.2	2.3	3.5	4.3
90	5	1.3	2.6	4.1	4.7	1.2	2.2	3.4	4.1
91	5	1.5	3.3	4.5	5.4	1.3	2.8	3.8	4.5
92	5	1.4	3.4	4.4	5.6	1.5	3.0	4.0	4.6
93	5	0.8	2.0	3.2	4.2	0.9	1.9	2.9	3.6
94	5	0.9	2.1	3.2	4.1	0.9	1.9	3.0	3.5
95	5	1.2	2.5	3.5	4.3	1.1	2.3	3.0	4.0
96	5	1.2	2.5	3.5	4.3	1.1	2.2	3.0	3.7
97	5	1.5	2.9	4.0	4.6	1.4	2.8	3.6	4.1
98	5	1.5	3.0	4.1	4.7	1.3	2.8	3.8	4.0
99	5	1.2	2.5	3.5	4.3	1.1	2.1	3.0	3.9
100	5	1.2	2.5	3.5	4.3	1.1	2.2	3.0	3.9

B=Blue singliline argon laser, BG= Bluegreen multilines argon laser.

Appendix IVb.-Statistic analysis (p-values) blueline versus multiline argon laser, at various spot sizes and exposure times.

spot size	5sec	10sec	15sec	20sec
1mm	0.030	0.001	0.001	0.001
2mm	0.000	0.001	0.001	0.001
3mm	0.103	0.001	0.001	0.001
4mm	0.002	0.001	0.001	0.001
5mm	0.001	0.001	0.001	0.001

Westmead and Parramatta Hospitals
and Community Health Services



CONSENT FOR RESEARCH

Title	Family Name	M.R.N.			
Given Names		C.M.O.			
Address	Street	Age	Sex	H.I.S.	
Suburb	Postcode	Adm. data			

Title of Project: Pulsed Nd:YAG Laser induced anaesthesia: A study comparing clinical efficacy and effects on the pulp with a topical anaesthetic (EMLA 5% cream).

Name(s) of Chief Investigator(s): Ambrose Chan

A study is to be carried out by Dr.A.K.Chan and Dr.A.Punmia-Moorthy, Department of Oral Surgery, University of Sydney, to evaluate the use of the Amercian dental laser (Nd:YAG) and a topical anaesthetic (EMLA 5% cream). Both are currently being used in Dental practice and have been found to produce loss of sensations to stimuli resulting in analgesia during tooth drilling.

Methods and Demands: In this study, only teeth requiring removal for Orthodontic reasons will be tested for the level of anaesthesia/analgesia attained. The tests will be carried out by an electrical pulp tester and by small test cavity drilling after laser or topical anaesthetic applications. Only two teeth will be tested at each visit and these teeth will be extracted immediately after tests under local anaesthesia.

Risks, Inconveniences and Discomforts Which May Occur:

The laser equipment used in this study has been used extensively in clinical practice without any reported serious adverse effects. The level of anaesthesia will be tested with an electrical pulp tester and drilling a small, simple cavity, which will take two to three minutes to complete. In both cases, only slight sensitivity or pulsating pressure is felt and the testing will be terminated, whenever slight pain is first felt. At the completion of the testing you will be asked to give a score to any pain you might have experienced.

I have been asked to participate in the above research study and give my consent by signing this form on the understanding that :

1. The research study will be carried out in a manner conforming with the principles set out by the National Health & Medical Research Council
2. The general purposes, methods and demands and the possible risks, inconveniences and discomforts which may occur during the study have been made known.
3. Refusal to take part in this study will not affect the treatment of my condition.
4. I am volunteering to take part in this study and I may withdraw at any time.
5. This research has been approved by the Western Sydney Area Health Service Research and Ethics Review Committees
6. The sponsoring pharmaceutical company and Drug Regulatory Authorities may have access to my medical records for the purpose of monitoring the research, however my identity will be protected.

Signature _____ Relationship _____ Date ____/____/____

(By subject if over 16 years : Otherwise please state relationship.

If adult subject unable to consent, by Guardian/spouse/de facto/caregiver/Guardianship Board.

If between 14-16yrs, subject plus parent to sign : If under 14yrs, parent or guardian to sign.)

Witnessed by: _____
of: _____

Project approval No: HREC/94/1/7.1

DATA SHEET

TOOTH	Agents	Ave. Power	EPT		CAVITY	PAIN
			PRELASE	POSTLASE	CUTTING	SCORE
	He:Ne &EMLA 5%					
	Nd:YAG &Placebo EMLA					

TOOTH	Agents	Ave. Power	EPT		CAVITY	PAIN
			PRELASE	POSTLASE	CUTTING	SCORE
	He:Ne &EMLA 5%					
	Nd:YAG &Placebo EMLA					

PAIN SCORE : Visual analog scale.

No PAIN

WORST POSSIBLE PAIN

Place a mark on the line to show how much pain you are having!

PAIN SCORE : Visual analog scale.

No PAIN

WORST POSSIBLE PAIN

Place a mark on the line to show how much pain you are having!

Appendix VI.1
Internation Association for Dental Research
Abstract presented at IADR meeting, Sydney, October, 1996.

IADR ABSTRACT 1996

Tooth Temperature Changes During Pulsed Erbium YAG Laser Ablation.

Author (s): A.CHAN, B.GILLINGS and A.PUNNIA-MOORTHY
(Faculty of Dentistry, U.of Sydney and Westmead
Dental Clinical School)

Presenting Author: A.CHAN

The recently developed Erbium YAG dental laser is claimed to cut cavities without heat. This study tested the claim by exposing caries-free extracted premolars to Er:YAG and Nd:YAG laser radiation and high speed bur cavity preparation while recording pulp temperature changes. The roots of freshly extracted premolars were removed and K-type thermocouples inserted in the buccal and lingual pulp horns. Each tooth was placed in a 37 °C water bath with the crown exposed to the atmosphere through a rubber dam to simulate the thermal environment of a natural tooth in an open mouth. A 2mm² area on the mesial or distal surfaces of 13 teeth was then subjected to 100mJ, 10 Hz pulses from an Nd:YAG laser for 60 sec., then 500 mJ, 10Hz pulses from an Er:YAG laser with water cooling for 60 sec. A cavity was cut with a high speed bur and water cooling in 6 teeth for 60 sec. The temperature changes were recorded on a multi-channel chart recorder and analysed statistically. The average rise in pulpal temperature over 60 sec. was 7.9 ±2.8°C for the Nd:YAG laser, 3.6±1.2°C for high speed drill and less than 2 °C for the Er:YAG laser. It was concluded that the Er:YAG laser has a high thermal safety margin when used to cut cavities. This study was supported by Emona Instruments P/L.

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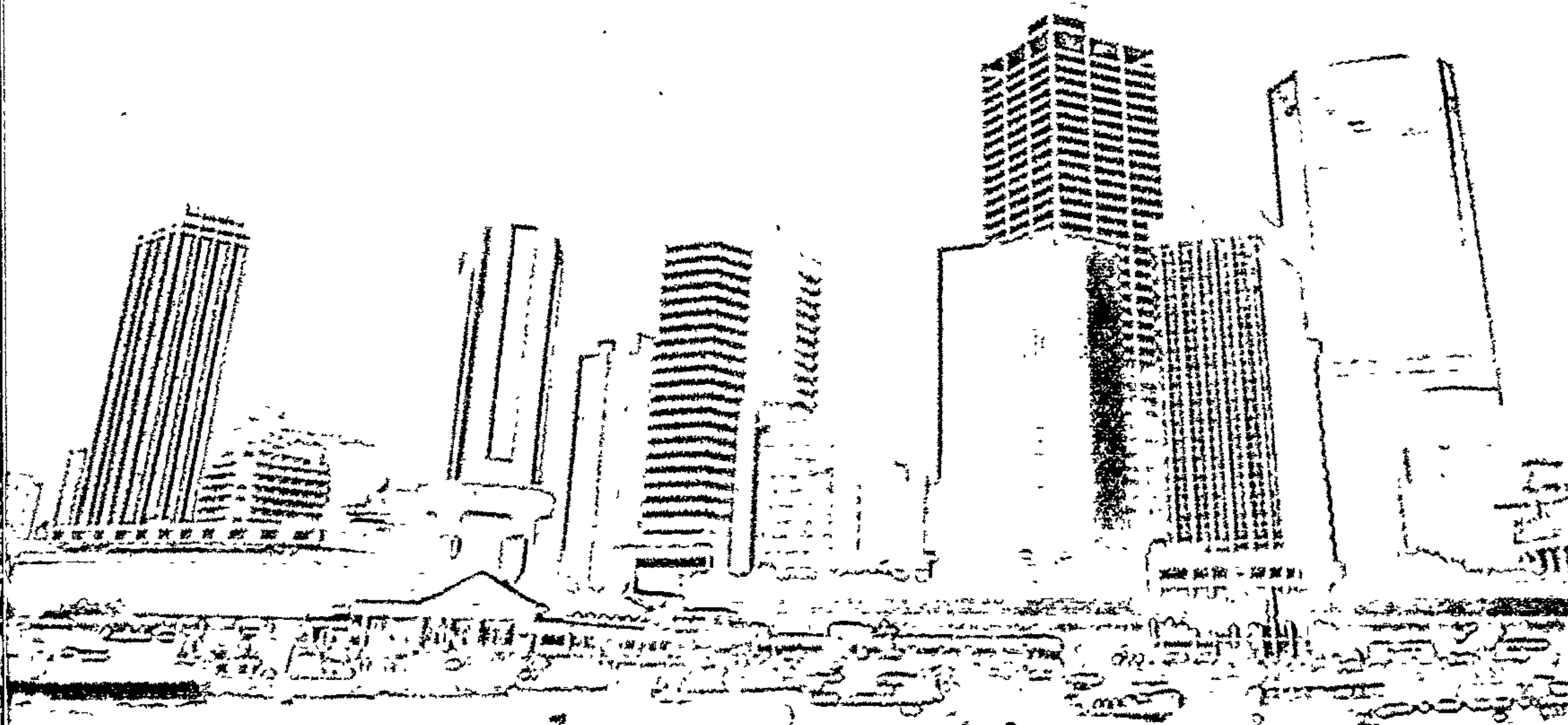
4th International Congress on

LASERS IN DENTISTRY

Singapore, August 6-10, 1994

Organizer

LOH HONG-SAI



MONDUZZI EDITORE

INTERNATIONAL PROCEEDINGS DIVISION

Pulpal anaesthesia induced by Nd:YAG laser and EMLA 5% topical anaesthetic cream. A comparative study

A. CHAN and A. PUNNIA-MOORTHY

*Discipline of Oral and Maxillofacial Surgery
Faculty of Dentistry, University of Sydney (AUS)*

SUMMARY

This preliminary, double blind, randomized study compared the depth of pulpal anaesthesia induced by Pulsed Nd:YAG Laser (American Dental) and EMLA 5% topical anaesthetic on bicuspid teeth. In 13 subjects, a pair of bicuspid teeth, from the same arch received a combination of test agents; EMLA 5% cream and He:Ne aiming beam or Placebo cream and Pulsed Nd:YAG Laser. After the application of the paired agents, the degree of anaesthesia was estimated by an Electric Pulp Tester and by drilling of a standardised Class V cavity. Results showed 9/13 cavities were complete in the EMLA group and 11/13 cavities were complete in the Laser group. The increase in Electric Pulp Tester readings from the baseline after application of either agents was statistically significant.

INTRODUCTION

The therapeutic applications of the Pulsed Nd:YAG Laser (The American Dental Laser) in clinical dentistry are numerous ^{1,2,3,4,7,8,9}. Laser induced anaesthesia is one of the useful application in clinical dentistry which offers a painless, simple and safe technique in managing needle-phobic and paediatric patients ^{5,6}. However, the mechanism and intensity of Laser induced analgesia are not well defined.

The aim of this present study was to compare the depth of pulpal anaesthesia induced by Pulsed Nd:YAG Laser and a potent topical anaesthetic, EMLA 5% cream, in a paired double blind, randomized manner.

MATERIALS AND METHODS

Thirteen subjects requiring extraction of bicuspid teeth for orthodontic reasons were investigated. In each subject, a pair of 1st or 2nd bicuspid, of the mandible or maxilla, were selected to receive a combination of test agents, namely EMLA 5% cream and He:Ne aiming beam or Placebo cream and Pulsed Nd:YAG Laser (American Dental). Laser was applied for 2 minutes each on the cervical halves of both buccal and lingual/palatal surfaces by roving contact, at a power range of 0.88-1.30W, at 15Hz, with a 320 micron fibre. The cream (0.5mg) was applied to the buccal sulcus adjacent to the tooth for 20 minutes and was secured by an Orahesive bandage. The degree of anaesthesia was estimated by an Electric Pulp Tester (EPT) and by drilling of a standardised Class V cavity of 2mm diameter and 1mm depth, at the centre of the buccal surface, with a highspeed rotary instrument. In all cases, the assessment was terminated when the pain was first felt and the pain experienced was immediately recorded using a visual analogue scale (0-100mm). EPT readings were taken at baseline and at 20 minutes after the application of the paired agents.

RESULTS AND CONCLUSIONS

Results showed a mean increase of EPT readings of 11.0 for EMLA group and 9.1 for Laser group (Fig.I). Nine cavities were complete in the EMLA group (69%) and 11 cavities were complete in the Laser group (85%) and the mean pain scores at the termination of drilling were 19.5mm and 25.5mm respectively (Fig.II). Statistical analysis using the Paired t-Test showed no significant difference between the groups, in terms of cavity depth and increase in EPT readings. However, the increase in EPT readings from the baseline after application of either agents (EMLA $p=0.002$, LASER $p=0.001$) was statistically significant (Fig.III).

In conclusion, this preliminary study provides clinical evidence of pulpal anaesthesia with the application of Pulsed Nd:YAG Laser and the depth of anaesthesia obtained was comparable to that produced by EMLA 5% topical anaesthetic cream.

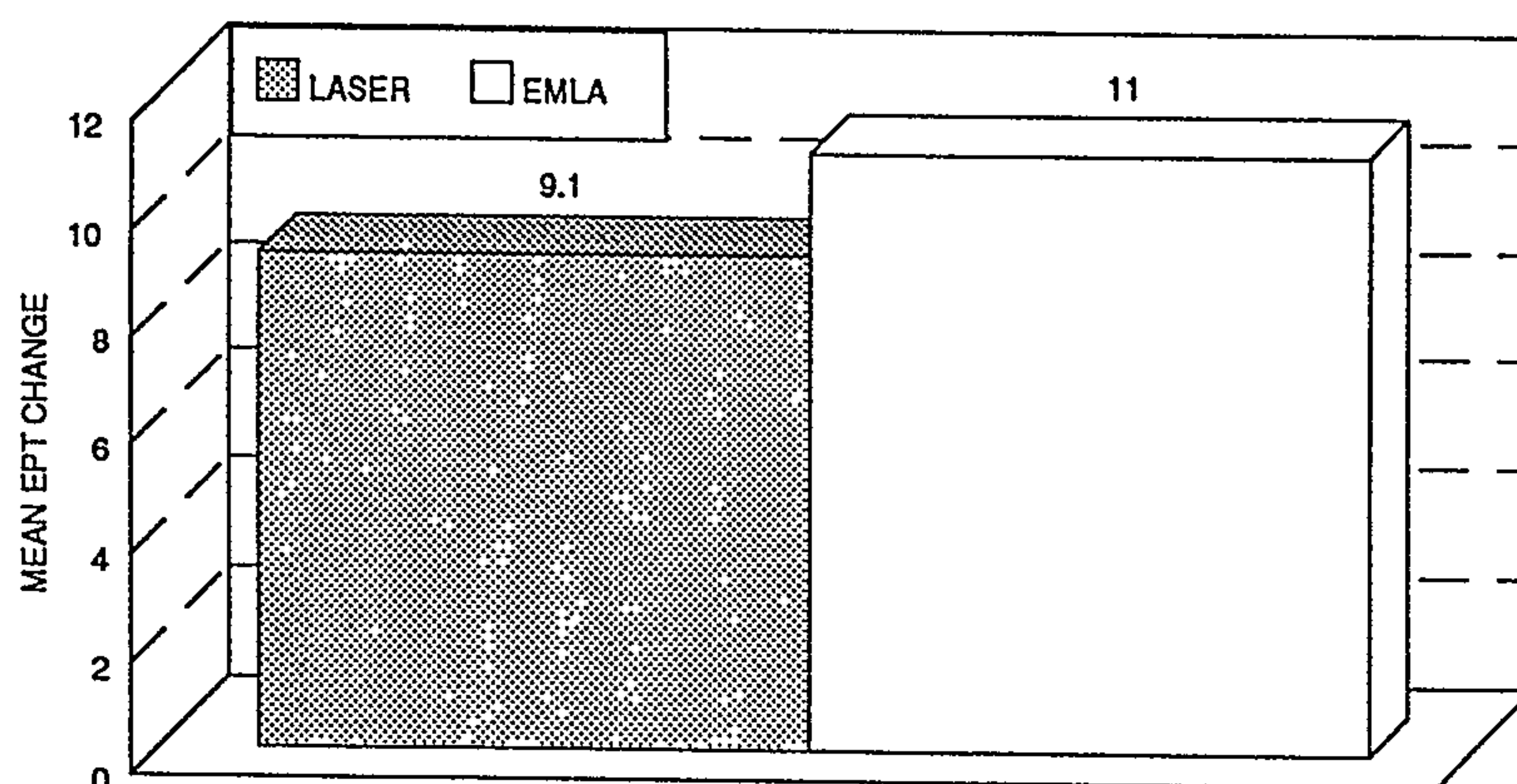


Fig. I-Mean EPT change: LASER versus EMLA

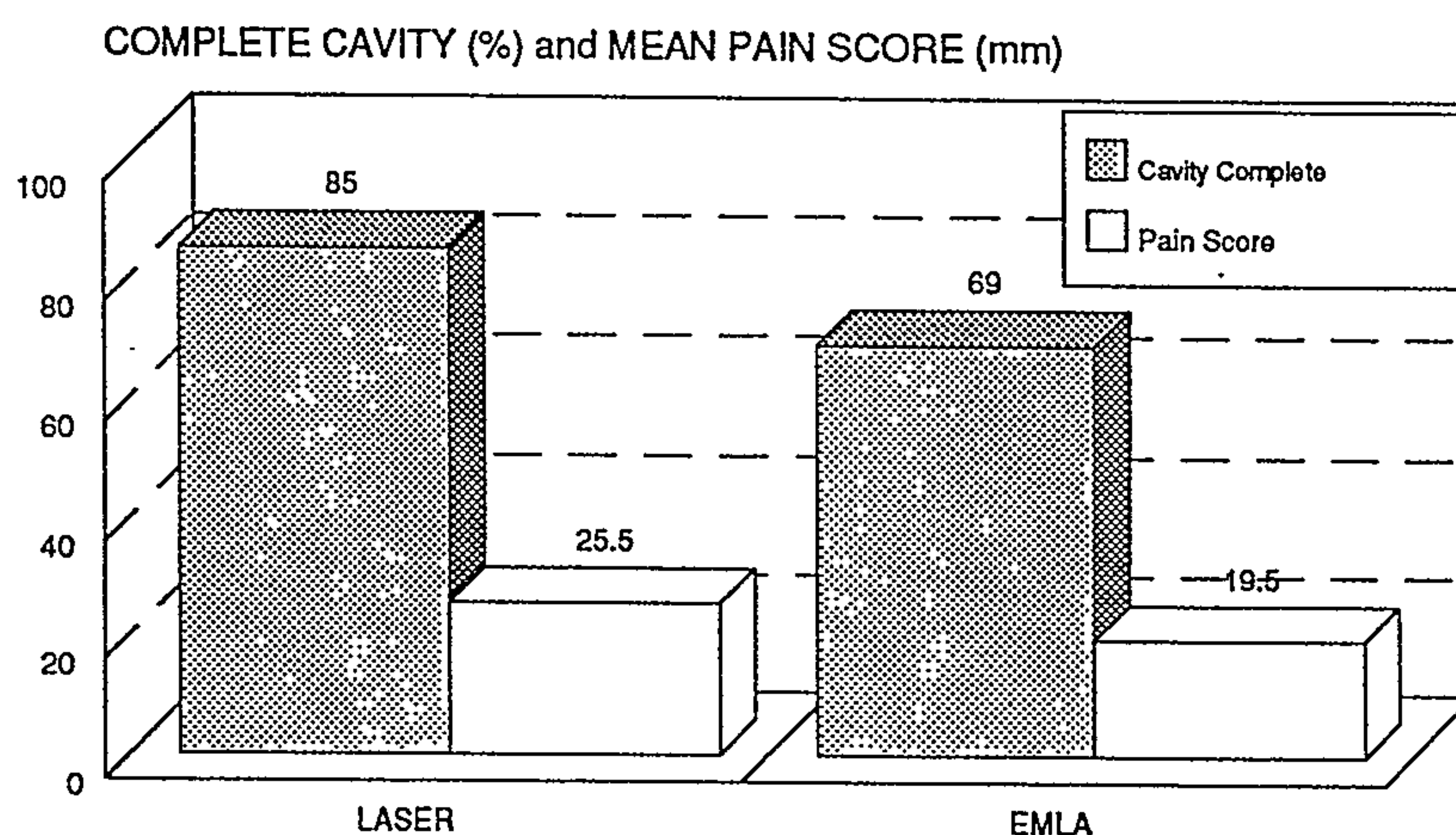


Fig. II-Complete cavity and pain score: LASER versus EMLA

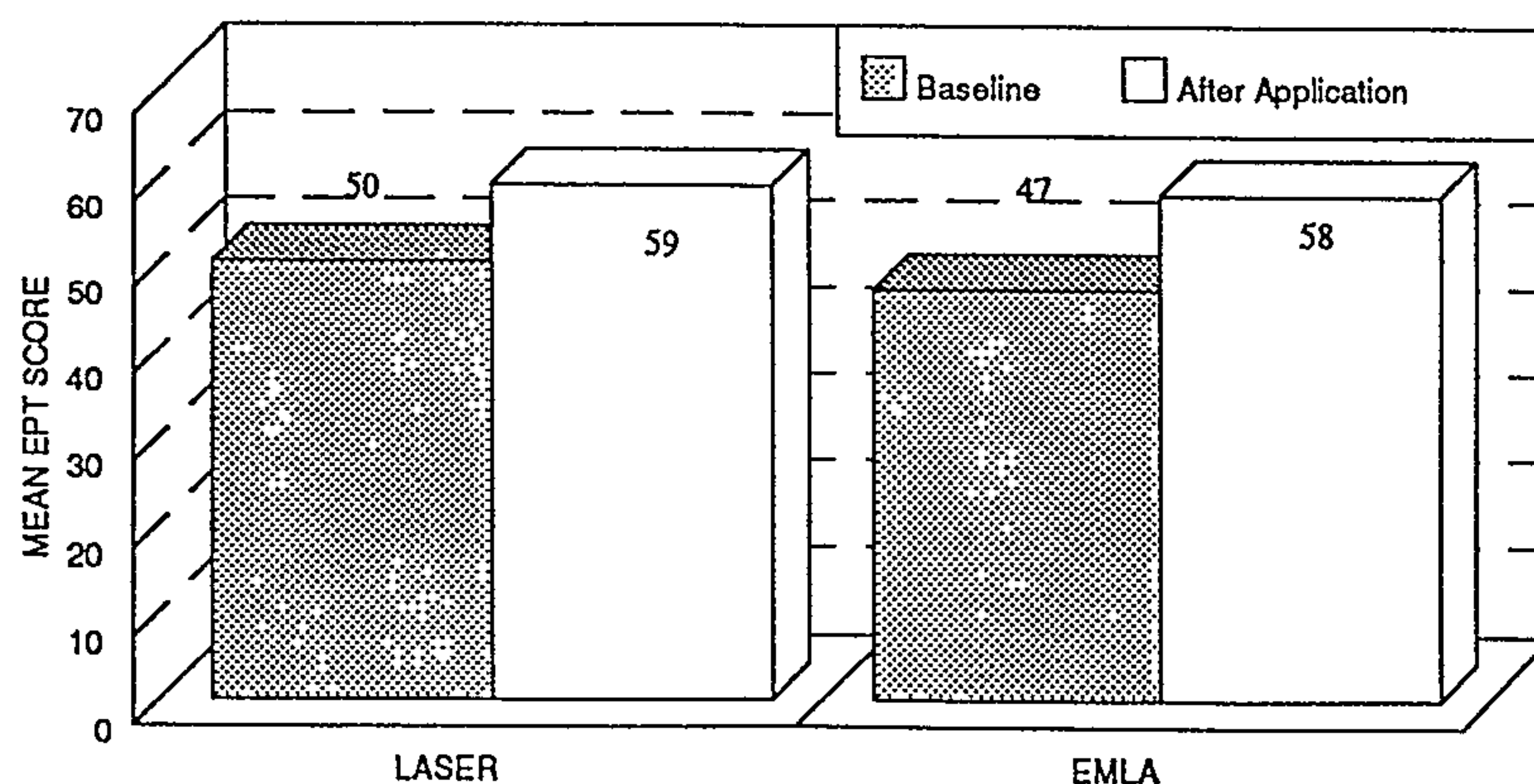


Fig. III-Before and after application: LASER versus EMLA

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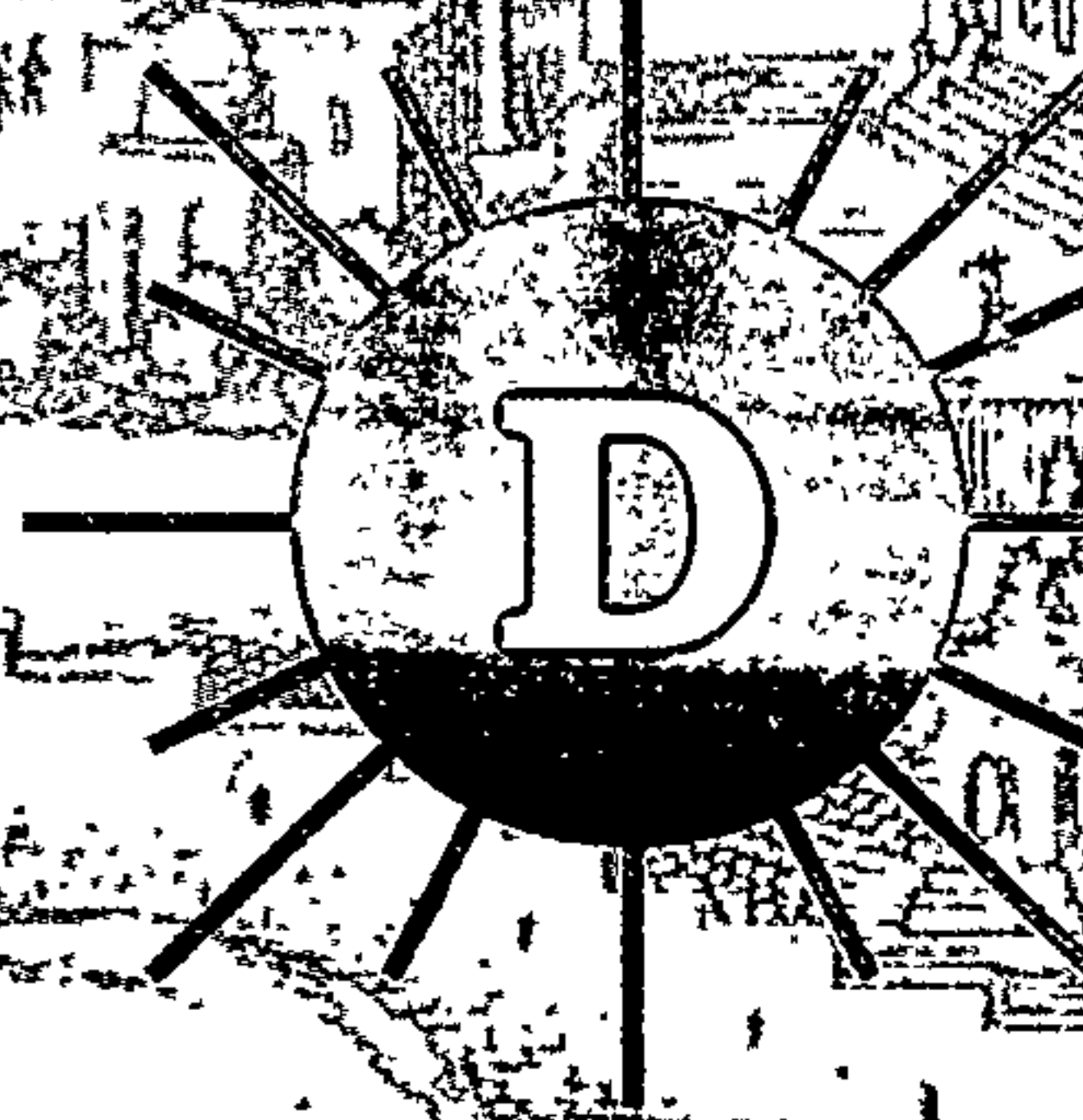
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5th CONGRESS OF THE INTERNATIONAL SOCIETY FOR LASERS IN DENTISTRY

Jerusalem (Israel), May 5-9, 1996

Editor

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The rise in intrapulpal temperatures: blue-line VS blue-green multilines Argon lasers

5th Congress of the
International Society
for Lasers in
Dentistry

Jerusalem, Israel
5-9 May 1996

A. CHAN and A. PUNNIA-MOORTHY

*Discipline of Oral and Maxillofacial Surgery
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SUMMARY

The purpose of this *in vitro* study was to compare the rise in intrapulpal temperature with blue-line and blue-green multilines Argon lasers, at different energy density (range :12-1200J/cm²), in human premolar teeth. Intrapulpal temperature was measured by embedding thermocouples into the pulp chamber. Each specimen received both wavelengths, alternately, in a random manner, of five selected spot sizes (1mm,2mm,3mm,4mm and 5mm), at 0.6W, and continuously for 20sec. Results showed statistically significant difference between the two wavelengths in terms of intrapulpal temperature rise for all spot sizes. However, the temperature rise for both wavelengths was less than the critical temperature of 5.5 °C, for all spot sizes, when the exposure time was less than 15sec (ie. with energy density <900J/cm²).

INTRODUCTION

The photo-absorption spectrum of light activated restorative materials has its peak around 480nm⁴. The Argon laser emits several wavelengths, namely the blue singleline (primarily 476 & 488nm) and blue-green multilines (primarily 476, 488 & 514nm), allowing the laser to activate photopolymerization of dental resin materials¹¹. Argon laser can polymerize composite resins at a faster rate^{3,6} and give better physical

properties of the cured resins as compared to the traditional visible light source 1,2,7,8.

Recent studies have shown that it is safe to irradiate enamel with Argon laser with energy density less than $900\text{J}/\text{cm}^2$, resulting in no pulpal or visible enamel damages and the change in intrapulpal temperature is less than 6°F . 9,13.

It had been demonstrated that the blue singleline and blue-green multilines are similar in terms of the diametral tensile strength of the cured resins 10.

The object of this *in vitro* study was to compare the rise in intrapulpal temperature at different energy density of blue singleline with the blue-green multilines Argon laser.

MATERIALS AND METHODS

Fifty human caries free premolar teeth, recently extracted for orthodontic reasons, were horizontally sectioned at the cemento-enamel junction. The pulpal content was removed and K-type bead thermocouples were embedded with thermopaste into the pulp chamber, directly opposite the buccal laser exposure site. The tooth thickness (mean: $2.8 \pm 0.2\text{mm}$) from the site of laser exposure to the thermocouple was determined radiographically. The prepared tooth was secured with the crown above the water level, in a water bath at 37°C to simulate intraoral temperature and humidity 5,12.

The Argon laser, an HGM model Dental spectrum 400, which emits both blue line and blue-green multilines and equipped with fiberoptic delivery system (600 microns fiber), was used in this study. Each tooth received both blue line and blue-green multilines Argon lasers, alternately, in a random manner, of five selected spot size (1mm, 2mm, 3mm, 4mm & 5mm), at an average power of 0.6W, continuously for 20secs. These teeth were randomly assigned into groups of 10 teeth for each spot size. The laser optical fiber was positioned and stabilized by rigid positioning jigs, so that the focal spot on the tooth surface corresponded to the test spot size. The changes in temperature from the baseline were continuously recorded with a chart recorder.

RESULTS AND CONCLUSIONS

Results showed a linear increase in temperature with the decrease in spot size and increase in laser exposure time. The temperature rise of both blue line (fig. 1) and blue-green multilines (fig. 2) laser wavelengths, within an exposure time of less than 15secs, at 0.6W average power, with spot sizes ranging from 1mm to 5mm (i.e. energy density $< 900\text{J}/\text{cm}^2$), was less than the critical temperature (5.5°C).

Statistical analysis using paired t-test showed significant difference ($P=0.05$) between blue line and blue-green multilines wavelengths in terms of change in intrapulpal temperature for all spot sizes. The mean temperature rise of the blue line readings was about 1°C higher than the blue-green multilines readings.

In conclusion, this *in vitro* study showed a greater rise in intrapulpal temperature with blue line than the blue-green multilines of Argon lasers, however, the temperature rise is under the critical temperature.

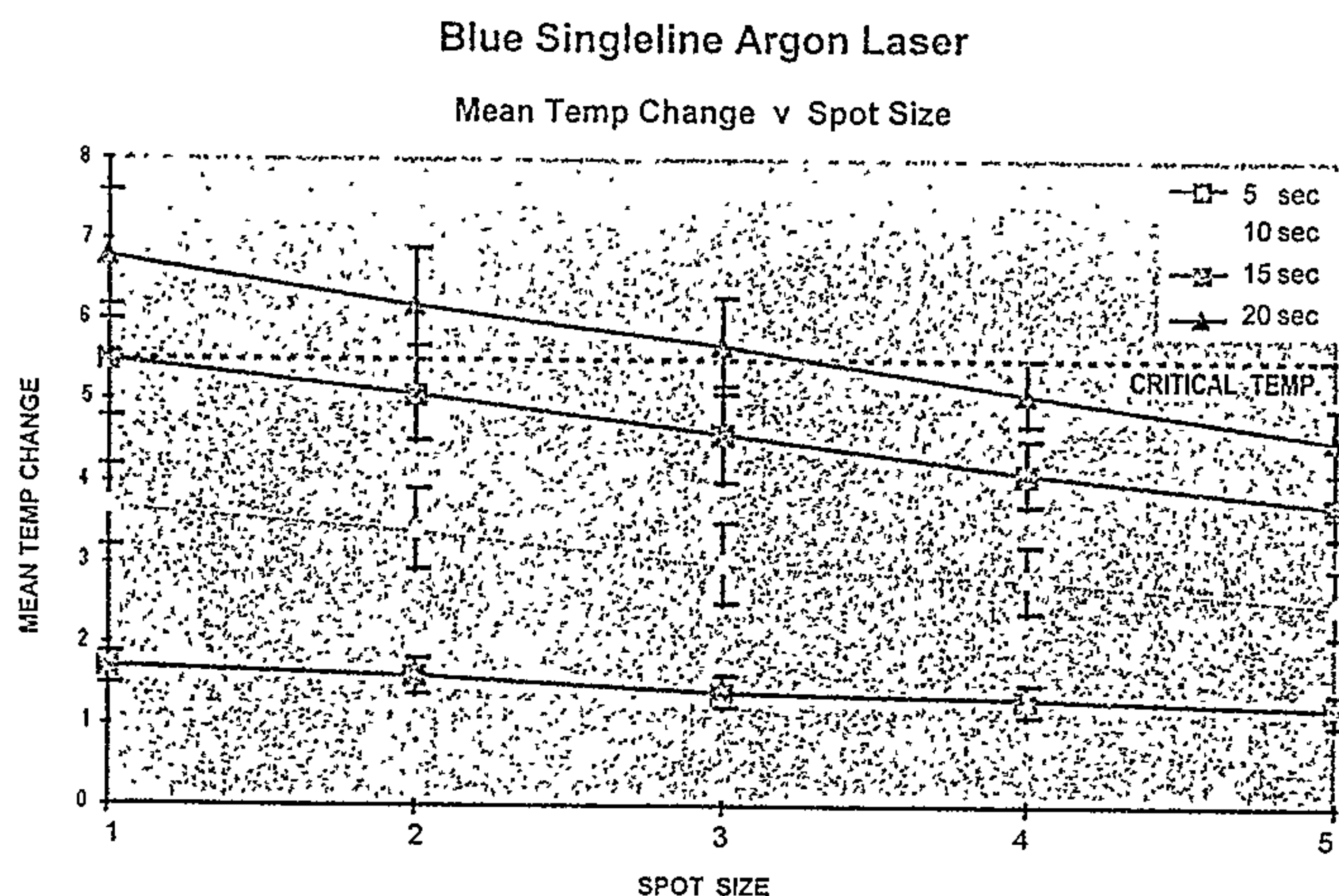


fig. 1

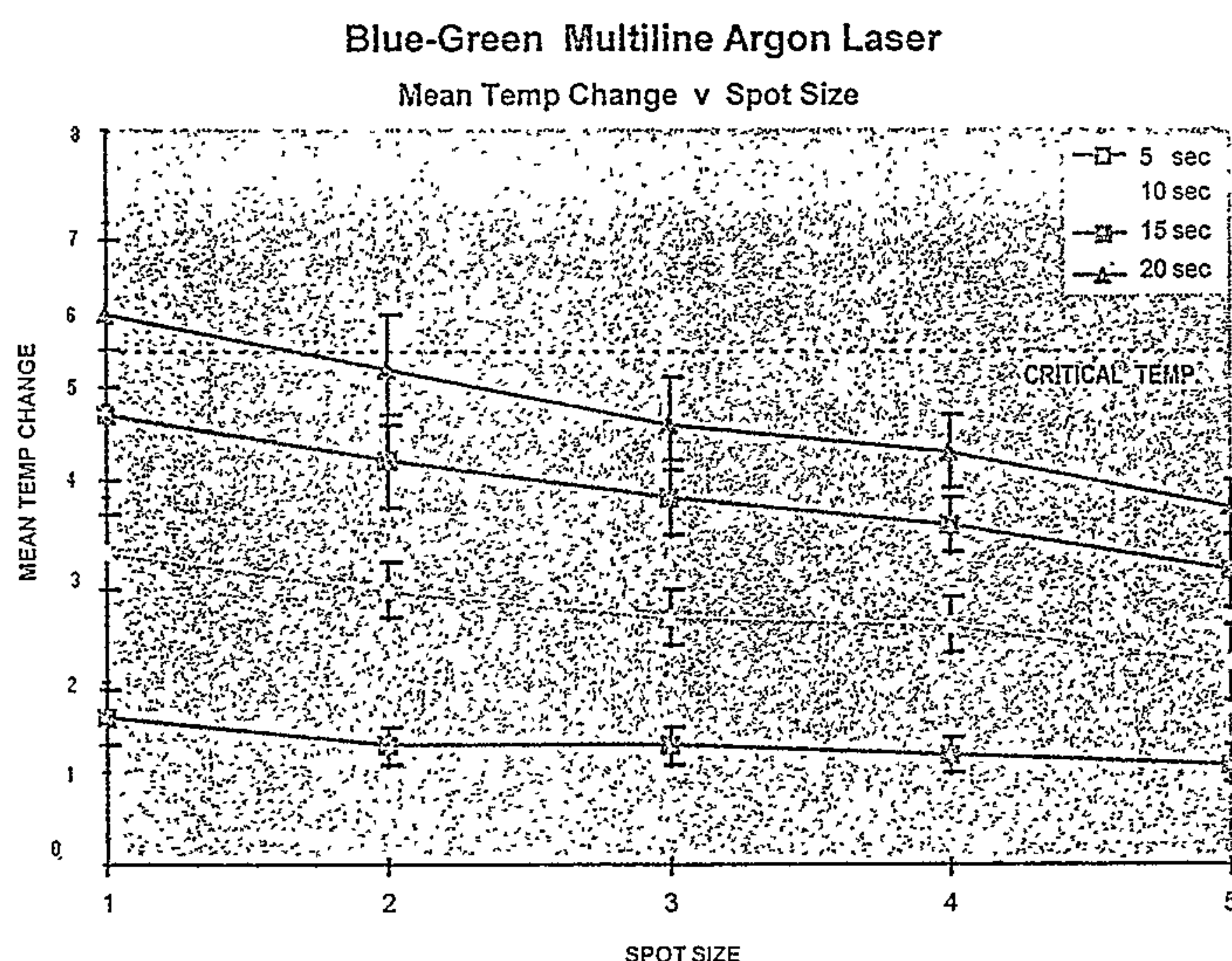


fig. 2

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