Ultrastructure of Er:YAG Laser-treated Human Dentine

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Purpose: The objectives of the present study were to determine the changes in the ultrastructure of human dentine resulting from simulated cavity preparation by an Er:YAG Laser, and to investigate the optimal parameters of that laser for ablating dentine.

Materials and Methods: Whole extracted caries-free human molars were used in this experiment. A slice of coronal enamel was removed to expose dentine above the pulp chamber. Irradiation was carried out using an Er:YAG laser with different combinations of energy levels, frequencies and pulse modes. Samples were then prepared for SEM analysis.

Results: Within the Er:YAG laser parameters tested, several characteristic features were evident on the dentine surface. The features included absence of smear layer, open dentinal tubules, microroughness, and crater-like appearance. It was also demonstrated that intertubular dentine is more prone to ablation compared to peritubular dentine. SEM analysis also indicated that the optimal parameters, which produced the cleanest and smoothest treated dentine surface, were around 250 mJ energy level, variable square pulse (VSP) mode, and 10 Hz frequency.

Conclusion: This study reported on some of the visible effects of Er:YAG laser treatment of dentine. Features such as open dentinal tubules, absence of smear layer and crater like appearance were similar to those effects noted in previous reports. However, other characteristics such as microirregularities and microprojections have not been previously described. The clinical relevance of the paper is that its findings validate the optimal performance parameters recommended by the manufacturer (Fotona Laser Systems).

Keywords: laser, dentine, surface morphology, SEM, optimal parameters.

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From an historical perspective, the early lasers for dental use resulted in undesirable side effects including excessive heat generation and melting of tooth tissue. More recently, a number of manufacturers have produced laser equipment that effectively removes diseased dental tissue with few side effects. The increased use of dental lasers has spurred investigations into the characteristics of laser-treated dental hard tissues, such as surface morphology,[8] acid resistance, microleakage,[2] and bond strength of adhesive materials.[3,7,9]

The mechanism of laser ablation of the softer dentine is in need of further clarification; to that end, the objectives of the current study were to examine the ultrastructure of human dentine following Er:YAG laser irradiation and to elucidate the optimal parameters of that laser for ablating dentine.

Fig 1 The removal of coronal enamel to expose the dentine.

MATERIALS AND METHODS

Whole extracted caries-free human molars stored in 0.5% aqueous chloramine T solution were used in this experiment. Coronal enamel was removed using a low-speed saw (Isomet, Buehler, Lake Bluff, IL, USA) to expose dentine above the pulp chamber as illustrated in Fig 1.

The laser device used was a Fidelis Surgical Laser, model 320A Er:YAG (Fotona Laser Systems, Ljubljana, Slovenia). The maximum and minimum energy output for this type laser is 600 mJ and 40 mJ, respectively, while the maximum and minimum frequency is 50 Hz and 2 Hz, respectively. At 50 Hz, the highest energy attainable was only 120 mJ. However, at 40 Hz, the energy peaked at 200 mJ. Both of these energy levels were with very short pulse mode (VSP). Other modes are short pulse (SP), long pulse (LP) and very long pulse (VLP).

The energy levels were set at 100, 150, 200, 250, 300, 350, 400, 450, 500, 550, and 600 (mJ). The frequencies were 5, 10, 20, 30, 40, and 50 (Hz), and a combination of VSP, SP, LP, and VLP modes were used.

Initially, the experiment aimed to determine the effects of different energy levels with one frequency (10 Hz) and one mode (VSP) on exposed dentine. Ten Hz and VSP were chosen because of the recommendation by the manufacturer. Under those parameters, the optimum energy level was determined. Then, using that optimum energy level, different frequencies were examined with only one mode. Lastly, different modes were tested using optimum energy and optimum frequency, with the intent of producing the optimum Er:YAG laser parameters for dentine preparation. Tables 1 to 3 show the different parameters tested.

Each specimen was hand held during irradiation, with the coronal cut dentine facing upwards. The laser beam was positioned parallel to the long axis of the tooth and perpendicular to the prepared coronal surface in the focus mode with approximately 0.5 mm spot size. The beam was moved back and forth. Water spray was used throughout the procedure. Using the different laser parameters listed above, four sites measuring 1 mm x 2 mm were ablated on each tooth. These four sites were located around the centre of the tooth (encircling the roof of the pulp chamber) as illustrated in Fig 2. Each specimen was then horizontally sectioned at about 3 mm from the coronal surface (Fig 3) with the low-speed saw (Isomet, Buehler) for SEM analysis.

For SEM analysis, each dentine specimen underwent fixing, washing, and dehydration prior to being attached to a metal stub and coated with gold. Analysis was carried out using a Philips XL 30 scanning electron microscope (FEI, Eindenhoven, The Netherlands) operated at an energy level of 10 kV. Images were magnified up to 10,000 times to provide the most effective analysis of morphological surface changes in dentine.

RESULTS

On each dentine specimen, laser ablation produced shallow crater-like lesions approximately 0.5 mm deep (Fig 4). Within these areas and with all possible combinations of the ER:YAG laser parameters tested, several characteristic features of the treated dentine were apparent.

SEM images showed that all treated dentine surfaces were free from smear layer, exhibiting open dentinal tubules (Fig 5). It was also clearly demonstrated that intertubular dentine was more prone to ablation compared to peritubular dentine (Fig 6). Other features included microroughness and, in some specimens, minute projections of dentine were observed (Fig 7). Additionally, it was found that as the parameters involving energy and frequency were intensified, ablation efficiency was also increased. For example, projections around dentinal tubules (Fig 6) were evident at lower energy levels (100 mJ); however, as energy levels were increased, further microirregularities appeared, especially in the area of intertubular dentine (Fig 7). With an increase in ablation energy, there was further degradation of the peritubular dentine, and the shape of the open dentinal tubules tended to become less distinct.

Table 1 Samples with different energy levels

Groups (n = 3)	Energy (mJ)	Frequency (Hz)	Mode
1	100	10	VSP
2	150	10	VSP
3	200	10	VSP
4	250	10	VSP
5	300	10	VSP
6	350	10	VSP
7	400	10	VSP
8	450	10	VSP
9	500	10	VSP
10	550	10	VSP
11	600	10	VSP

Table 2 Samples with different frequencies

Groups (n = 3)	Energy (mJ)	Frequency (Hz)	Mode
1	250	5	VSP
2	250	10	VSP
3	250	20	VSP
4	250	30	VSP
5	200	40	VSP
6	120	50	VSP

Table 3 Samples with different modes

Groups (n = 3)	Energy (mJ)	Frequency (Hz)	Modes
1	250	10	VSP
2	250	10	SP
3	250	10	VLP
4	250	10	LP

SEM analysis also suggested that the optimal parameters, which produced the cleanest and smoothest treated dentine surface, were around 250 mJ energy, variable square pulse (VSP) mode, and 10 Hz frequency (see Fig 5). Figures 4 to 7 show some examples of SEM images of human dentine surface morphology following Er:YAG laser irradiation.

DISCUSSION

With respect to the adhesion to dental hard tissue after laser ablation, Visuri et al,[9] using an Er:YAG laser operating at 350 mJ and 6 Hz, observed that the laser-etched surface yielded stronger bonds between composite resin and dentine than with a traditional handpiece with or without acid etching. Principally, these au-

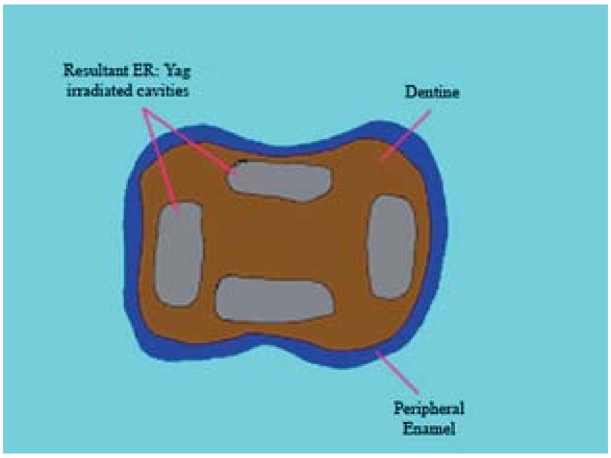

Fig 2 Coronal view of specimen after Er:YAG laser ablation.

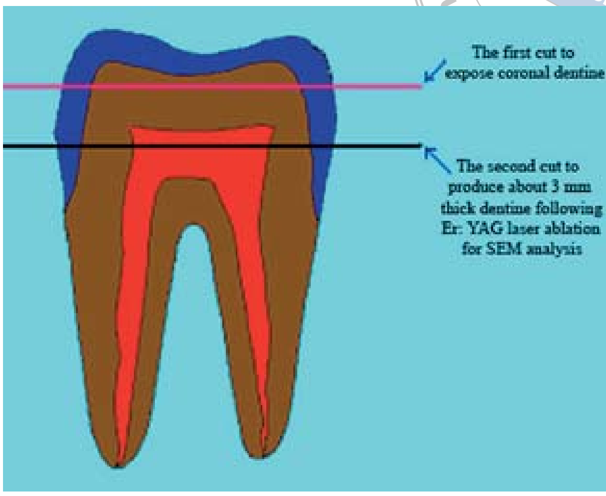

Fig 3 Illustration showing the level of sectioning for SEM analysis.

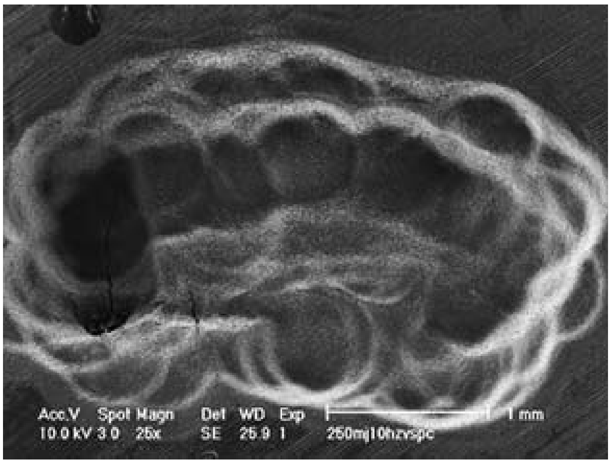

Fig 4 SEM image showing rounded crater-like structures following Er:YAG laser irradiation at 250 mJ, VSP, and 10 Hz (25X magnification).

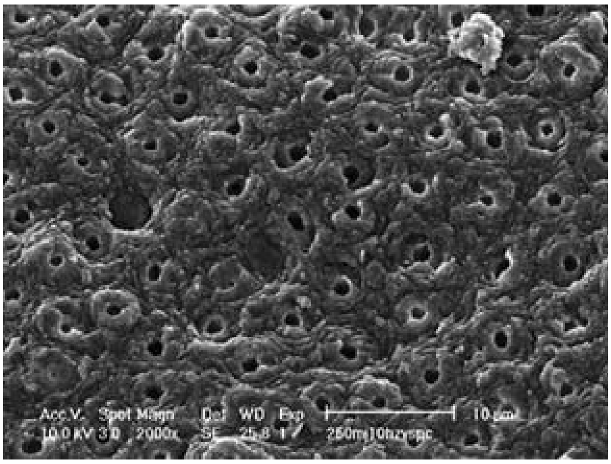

Fig 5 SEM image demonstrating the typical surface features of an Er:YAG laser treated dentine surface: no smear layer and open dentinal tubules; parameters 250 mJ, VSP, and 10 Hz (2000X magnification).

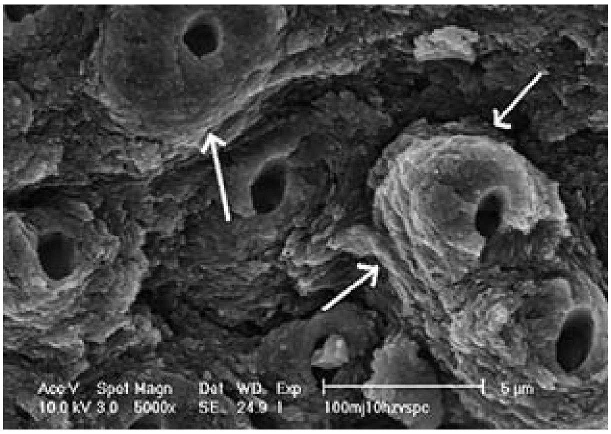

Fig 6 SEM image of surface irregularities, selective ablation of intertubular dentine vs peritubular dentine and microprojections from the surface (white arrows); parameters 100 mJ, 10 Hz, and VSP (5000X magnification).

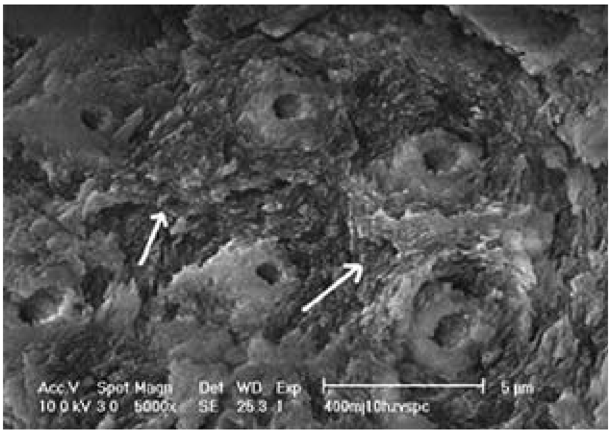

Fig 7 SEM image highlighting further surface degradation and an increase in microirregularities on an Er:YAG laser-treated dentine surface; parameters 400 mJ, 10 Hz, and VSP (5000X magnification).

thors felt that the laser eliminated the need for acid etching, as the production of open dentinal tubules produced an ideal surface for bonding resin. However, Oho et al[6] found that Er:YAG laser etching produced inferior bond strengths to dentine compared with acid etching; ostensibly, laser ablation produced extensive subsurface fissuring of the dentine. Giachetti et al[5] cautioned against the use of Er:YAG laser ablation as a substitute for conventional acid etching. Chinelatti et al[4] concluded that the use of Er:YAG laser for cavity preparation negatively affected the marginal seal of Class V resin-modified glass-ionomer restorations.

The discrepancy between studies that suggest laser etching produces good bond strengths to dentine vs other reports of low adhesion can be firstly explained by differences in laser energy and frequency which can produce topographical surface differences. Secondly, some studies use a very dilute solution of thymol for storing teeth while others use formalin; the latter may result in collagen degradation and hence a change in bond strength. As a general rule, major differences in experimental design make direct comparison of bond strengths impossible.

The cylinder-like projections around dentinal tubules as shown in Fig 6 could be explained through differences in composition between peritubular and intertubular dentine. It is well established that as their positions are closer to odontoblastic processes, peritubular dentine contains more mineral than its intertubular counterpart. Higher mineral content together with a reduction in water composition means that laser ablation will not be as efficient.

Typically, laser-treated dentine exhibits open dentinal tubules with no smear layer (Figs 5 and 6). It is well known that a smear layer covers dentine prepared with a dental bur and sensitivity can be present. However, the nature of the ablated dentine surface and the interplay that allows the laser to produce pulpal analgesia is subject to much conjecture. Birardi et al[1] suggested that analgesia might be produced by a reduction in dentine permeability. Unfortunately, the SEM images of open dentinal tubules do not provide information on the mechanism of this process. They may suggest that shrinkage of the odontoblastic processes in the dentinal tubules together with degeneration of nerve fibre endings decreases pain when using the laser.

CONCLUSION

The manufacturer's recommendation with respect to optimal settings for Er:YAG laser ablation was confirmed. However, certain dentine surface characteristics produced during laser ablation, such as microdamage, may be detrimental to resin bonding procedures.

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