Fusion of inorganic materials to enamel and porcelain surfaces with Nd:YAG laser

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Purpose: The aim of this study was to examine condition concerning fusion of inorganic material to enamel and porcelain surfaces by means of Nd:YAG laser.
Materials and Methods: Iron oxide was added to dental porcelain material in a range from 0.6 to 5.0% by weight. Slurry was placed on the human enamel and dental porcelain surfaces and Nd:YAG laser was exposed with varying energy and exposure time periods.
Results: Melting of material occurred with the following irradiation condition; 40 W for 4 s for 0.6% iron oxide, 20 W for 2 s for 2.5% and 5% iron oxide. Fusion of the material occurred with specific conditions. However, degeneration or degradation of tooth substrate also was detected with high energy and extended exposure period.
Conclusion: It was possible to fuse an inorganic substance to enamel surface using Nd-YAG laser. Further investigation is required about materials, type of laser, and irradiation condition.
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Key Words: ceramics, enamel, fusion, iron oxide, laser, porcelain.

Introduction

The application to dental practice of laser has increased substantially.[1-9] This trend is mainly attributed to development of varying laser apparatus for surgery and dental laboratory. Neodymium-doped yttrium-aluminum-garnet ($Y_3Al_5O_{12}$, Nd:YAG) laser has been used for welding nickel-chromium alloy,[10] treating apical focus,[11] drilling zirconia implant material,[12] soft tissue surgery,[13] and metal-ceramic bonding.[14] It is necessary for clinicians to keep in mind adequate type of equipment, energy, focus mode, and exposure time period, in application of laser devices. Fusion of inorganic material to tooth surface using laser is novel approach associated with preventive and restorative dentistry. Although, several reports have been published on fusion of dental materials to tooth structure, and surface texture of lased enamel,[1-3] only limited information is available about the relation between materials to be fused and exposure conditions of specific type of lasers. This study aimed to evaluate the relation between composition of inorganic materials and melting condition using a Nd:YAG laser apparatus. Behavior of fusion to enamel and porcelain of materials also was examined.

Materials and Methods

Dental porcelain (Dentin A2, Opaque A2), aluminum oxide, hydroxy-apatite as well as two additives, cadmium red and iron oxide were assessed (Table 1). Additives were added to the inorganic materials 0.6-5.0% by weight. A Nd:YAG laser apparatus (Model 8000, Molectron Medical; currently Coherent Inc., Santa Clara, CA, USA) was used as an energy source. The diameter of the probe was 0.6 mm, and the diameter of the circular area to be irradiated can be calculated by the following equation; Diameter = DT x tan10˚ x 2 + 6, where DT is the distance between the aperture of the probe and the surface to be irradiated. According to the equation, the irradiation diameter can be estimated as 16.6 mm when the distance between the probe aperture and the surface is 30 mm. Accumulated energy (ACE) can be calculated by the following equation; ACE = PP x PD x

NP (Ws), where PP is pulse power (W), PD is pulse duration (s), and NP is number of pulses. The current experiment used continuous radiation mode instead of pulsed radiation mode.

Table 1. Materials assessed.

Materials	Composition	Manufacturer
Dental porcelain, VMK Dentin A2	SiO_2, Al_2O_3, K_2O, MgO	Vita Zahnfabrik, Säckingen, Germany
Dental porcelain, VMK Opaque A2	SiO_2, Al_2O_3, K_2O, TiO_2	Vita Zahnfabrik
Aluminum oxide	Al_2O_3	Kyocera Inc., Kyoto, Japan
Hydroxy-apatite	$Ca_{10}(PO_4)_6(OH)_2$	Synthesized
Additive, Cadmium red	CdS, CdSe	Wako Pure Chemical, Osaka, Japan
Additive, Iron oxide (III)	Fe_2O_3	Wako Pure Chemical

Two additives were separately added to the three inorganic materials, mixed and slurry was prepared with distilled water. Approximately 0.05 g of the slurry was placed on either the white ceramic plate made of dental porcelain material (VMK Dentin A2) or ground human enamel. The laser was irradiated by means of the Model 8000 Nd:YAG apparatus with 0-60 W energy, 2.0-9.9 s exposure period, and 30 mm distance. Formation of solid after laser exposure was judged as melted. The specimens judged as fused were cut perpendicularly with a low-speed cutting saw (Isomet, Buhler Ltd., Lake Bluff, IL, USA). The specimens were observed under light and scanning electron microscope. The specimen without gap formation more than a half-length along the interface was categorized as fused. In addition, change in temperature on the specimen surface during laser irradiation was determined with a radiation thermometer with a surface-aperture distance set at 10 cm.

Results

Among the four inorganic materials, opaque porcelain, alumina, and hydroxy-apatite were difficult to melt or fuse under the conditions examined. Solid structure was obtained from the dentin-shade porcelain material with iron oxide. Cadmium red was ineffective as an additive for solid formation of ceramic materials.

Table 2. Melting and fusion of dentin-shade porcelain with iron oxide (III) after laser irradiation.

Iron oxide (%)	Energy (W)	Exposure (s)	2.0	4.0	6.0	8.0	9.9
0.6	20		N	N	N	N	N
0.6	40		N	Melt	Melt	Melt	Melt
0.6	60		N	Melt	Melt	Melt	Melt
1.2	20		N	N	N	N	N
1.2	40		N	Melt	Melt	Melt	Melt
1.2	60		N	Melt	Melt	Melt	Melt
2.5	20		Melt	Melt	Melt	Melt	Melt
2.5	40		Melt	Melt	Fused	Fused	Fused
2.5	60		Melt	Fused	Fused	Fused	Fused
5.0	20		Melt	Melt	Melt	Melt	Melt
5.0	40		Melt	Melt	Fused	Fused	Fused
5.0	60		Melt	Fused	Fused	Fused	Fused
Change of temperature (˚C) at 40 W, 10 cm			+9.5	+19.0	More than 20.0		

Underlying substrate, Dental porcelain material (VMK Dentin A2); N, Not changed; Melt, Solid structure was formed; n=5.
Accumulated energy varied from 40 Ws (20 W by 2.0 s) to approximately 600 Ws (60 W by 10 s).

Table 2 shows the change of structure of the dentin-shade porcelain material with iron oxide. Under the condition of the current experiment, formation of solid occurred when the dentin-shade porcelain material (with 0.6 or 1.2% iron oxide) was irradiated for 4.0 s or more with 40 or 60 W. Also, melting of porcelain material (with 2.5 or 5.0% iron oxide) occurred after 2.0-s irradiation with 20 W. Fusion to substrate of porcelain material occurred after 6.0-s irradiation with 40 W or after 4.0-s irradiation with 60 W for the dentin-shade porcelain with 2.5 or 5.0% iron oxide. Fusion to enamel was detected with the same condition as for the porcelain material (Fig. 1). The cut surface, however, demonstrated degeneration or degradation of tooth structure especially along the dentino-enamel junction

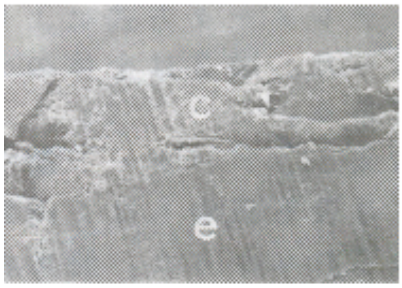

Fig. 1.
Scanning electron micrograph of lased porcelain and enamel.
c; Porcelain material with 2.5% Fe_2O_3.
e; Enamel.
Irradiation; Nd:YAG, 40 W, 6.0 s.

Discussion

This study evaluated the conditions concerning fusion of inorganic material to enamel and porcelain surface by means of Nd-YAG laser. Melting, fusion, and other phase transformation of inorganic compound by laser irradiation are dependent on color of surface to be irradiated. The authors used iron oxide (III) and cadmium red as coloring agents, i.e., pigments in this experiment. As shown in the results, addition of iron oxide was effective for melting and fusion of dental porcelain. On the contrary, opaque porcelain, hydroxy-apatite, and alumina were difficult to melt within the conditions employed. One of the reasons for this unfavorable result with opaque porcelain is the whitish color of the opaque porcelain. Reflection of laser by white pigment in the opaque porcelain may affect melting of compounds inside the material. In addition, it is likely that color of metal oxides and metallic compounds will change to a metallic color after high-energy application. The authors speculate that metallic colored substances are easier to fuse tooth surface rather than tooth colored substances. Care must be taken therefore to select inorganic compounds to be fused to tooth structure.

Melting temperature of compound is obviously an important factor for fusion to substrates of materials. Phase transition temperature of alumina is above 1,000˚C. The temperature is difficult for the material to be fused to other substrates. Hydroxy-apatite and enamel may be easier to decompose by irradiation of high-energy laser, since it is an ionic compound with two hydroxyl groups. It may be beneficial to use alkaline substance like a flux to reduce melting temperature of compound. Also, basic compounds, if applicable, may reduce acidity of tooth surface, in which activity of streptococci associated with dental caries will be reduced.

The type of laser apparatus plays a critical role in fusion of material to tooth structure. Several factors, wavelength, energy, focus setting, and surface temperature etc. should be considered for selection of laser apparatus in dental practice. Of these, difference between focused and defocused settings, and distance between aperture and the surface obviously influence characteristics of the irradiated surface. Although attempts at fusing ceramic material to enamel surface were basically unsuccessful within the limitation of the current experimental settings, the results of the current study suggested the possibility of fusion of inorganic materials to tooth structure using laser apparatus. Control of energy distribution of lased surface is another important factor for laser surgery. In particular, control of temperature around pulp and dentin is important. Irradiation of the

40-W Nd:YAG laser for 6.0 s induced degeneration of organic phase of dentin. Further investigation about materials, type of laser, and irradiation conditions is required.

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