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The Use of Nd: YAG Laser for Ablation of Dental Material

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Abstract. The effect of Nd: YAG laser pulses with a wavelength of 1064nm and 3mm of beam diameter on dental tissue enamel contains an adhesive material (transbond plus self-etching primer) is studied. Laser provides an ability to accurately deliver a large amount of energy into a confined regions. Additionally, Field Emission Scanning Microscopy (FESEM) and Energy Dispersive X-ray (EDX) are used to analyze the physical and chemical characteristics of raw teeth, teeth with an adhesive and teeth after laser irradiation. Sample was irradiated at 1.5Hz of pulse rate, 200ms of pulse width and 150J cm^{-2}, 200J cm^{-2}, 250J cm^{-2}, and 300J cm^{-2} of energy fluence. The effects of using multiple settings of fluence are discussed. It is demonstrated that, the ablation threshold for adhesive materials are much lower than the fluence threshold laser for enamel and higher with thicker adhesive material. Besides, x-ray energy dispersive spectroscopy (EDX) analysis of enamel indicates several elements include oxygen, phosphorus, calcium, silicon, and carbon on raw teeth. Considering the thickness of the transbond plus self-etching primer and the high pulse Nd: YAG laser, it is demonstrated that the effective ablation is between 250-300J cm^{-2}. In conclusion, Cynosure Cynergy Nd: YAG laser has high potential in removing dental adhesive material and therefore it can be used clinically.

Keywords: Nd: YAG laser, self-etching primer, field emission scanning microscopy (FESEM), energy dispersive x-ray (EDX)

1. Introduction

Laser was first introduced to the public in 1959 in an article by Columbia University. Laser stands for "Light Amplification by the Stimulated Emission of Radiation" and it has been used in dentistry and medicine application since early 1960s. Thedore Miaman introduced laser application in dentistry, such an application of hard and soft tissue applications using a mixture of helium and neon. There are several types of laser such as carbon dioxide (CO_2) laser, Neodymium Yttrium Aluminium Garnet (Nd:YAG) laser, Erbium (Er) laser, and diode laser with various functions of each. These types of laser can be divided into two scenarios, which are hard laser such as, Carbon Dioxide (CO_2) laser and Nd:YAG laser. Er: YAG laser is used for both hard and soft tissue applications. Unfortunately, the Er:YAG laser has limitation due to high cost and potential for thermal injury to the tooth pulp [1].

Other than that, lasers are indicated for a wide variety of procedures in dental practice considering the ease of use, efficiency, specificity, comfort, and cost over conventional modalities. In dentistry application, the use of laser can be classified into various methods, which are according to the leasing, medium used such as gas laser and solid laser according to tissue applicability. This (Nd:YAG) laser wavelength, highly

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absorbed by the pigmented tissue and make it very effective surgical laser for cutting and coagulating dental soft tissue with good homeostasis.

The laser plays an important role in many areas of technology. There are many functions of laser radiation, such as in welding, cutting and drilling. Besides that, laser radiation is used in modification of the physical and chemical microstructure of a materials [2]. Laser ablation is defined as the mass removal by coupling laser energy to a target material. Thermal and optical properties of the material will affect the ablation process. Additionally, this ablation process also depends on laser parameters, such as wavelength, laser intensity and pulse duration.

The purpose of this study is to analyse the application of pulsed neodymium laser. This Nd: YAG laser is used to ablate the remaining adhesive material on the human teeth. As we know, optical characteristics of hard tissue of the human teeth are significantly important in modern dentistry. These optical properties are native that characterize biological tissue, which does not depend on the geometry of the structure of teeth. The optical properties of dental tissue components resolve the nature and degree of the tissue reaction through the process of absorption, reflection, transmission, and scattering of the light [3]. These processes caused by the interaction of laser with human teeth.

Furthermore, bonding orthodontic brackets to the tooth surface is a necessary procedure in orthodontic clinical treatment. It is a temporary b0ond since the brackets will be removed after an active treatment. A target for orthodontic treatment is to heal the enamel surface to its original state after removal of orthodontic attachment. Braces compose of a bracket that bond to the teeth with a threaded by arch wires through the bracket. There are several types of orthodontic braces that available in the market, which are metal braces, ceramic tooth coloured braces and clear plastic or ceramic braces.

In addition, the braces are purposely used to correct malocclusions, such as underbites, overbites, cross bites and open bites. Other than that, it used for crooked teeth and various other flaws of teeth and jaws whether for cosmetic or structural purposes. Using orthodontic adhesive material, the braces are bonded to the surface of teeth. Then, it will lead to an activity caused by direct bonding of the orthodontic bracket with tooth enamel. There are many types of bonding agents developed to overcome this problem, includes resins, conventional glass ionomer cements, resin modified glass ionomer and polyacids modified composites [4]. These bonding agents provide different polymerization mechanism, such as chemical, light or dual curing.

2. Materials and Methods

2.1. Sample Preparation

Clean tooth sample was prepared by removing all debris using a brush. By using IsoMet Low Speed Saw, the clean tooth was cut into two. During the cutting procedure, it is important to aware that preparation of the tooth may change the microstructure of the tooth. For example, it may caused mechanical damage of the tooth. Then, the tooth sample was ready for mounting procedure. To make a mounting for the tooth, correct amounts of resins and hardener were measured carefully by volume. After mounted, surface layer of the tooth was covered with the resin. The sample surface was then polished through grinding procedure. The mounted tooth was ground using a rotating disk of abrasive paper flushed with a suitable coolant to remove debris and heat.

2.2. Sample Irradiation

In this study, Nd: YAG laser was used to remove the adhesive material. Laser beam was focused onto the front surface of the enamel and the adhesive material to produce a spot diameter of 3mm. A standard physical setting has been set up to ensure proper standardization for the sample irradiation process. For the first irradiation, laser parameter was set up with a fluence of 100J cm^{-2}. Next, the irradiation had been done on the other sample with a fluence of 200J cm^{-2}, 250J cm^{-2} and 300J cm^{-2}.

2.3. Sample Analyzation

The samples were assessed visually at up to x1k magnifications using FESEM. The FESEM was used to analyze the surface morphology of the sample while EDX was used to determine the element composition that present in the sample in terms of atomic percentage (at. %) and weight percentage (wt. %).

3. Result and Discussion

Teeth sample was analyzed using Field Emission Scanning Electron Microscopy (FESEM) and Energy Dispersive X-ray (EDX). EDX has been used for elemental analysis at the structural level of the enamel tooth. This technique, known as a micro-analytical technique was used in conjunction with FESEM. The FESEM was used to analyze the structure of the tooth while the EDX was used for elemental analysis [5]. In other words, FESEM was used to evaluate the complex surface structure of the enamel or the surface morphology of the enamel. The enamel surface will visualize at the submicron level. In this study, FESEM was used to examine the enamel surface which are the raw tooth without adhesive. Then, the enamel surface with Transbond Plus Self Etching Primer and finally the changes of the enamel surface after Nd:YAG laser irradiation with various energy fluences. Although there were several limitations using FESEM, the effectiveness of various method and instruments on the topography and morphology of the tooth surfaces were best examined under FESEM [6].

The FESEM can visualize very small topographic details on the surface of the tooth. The principle is based on how much the energy or the electron liberated from field emission source and accelerated in a high electric field gradient. In high vacuum column, these so called primary electrons were focused and deflected by electronic lenses. Then, a narrow scanning beam that bombarded the object was produced. As a result, secondary electron emitted from each spot on the tooth. The surface structure that was imaged, depends on the angle and velocity of the secondary electron. The secondary electron produced will leave the vacancy and filled by an electron from a high shelf. Then, an x-ray (characteristic x-ray) is emitted to balance the energy difference between two electrons. The EDX measure the number of x-rays emitted vs. their energy.

3.1. Adhesive Effect

Fig. 1a shows the surface morphology of a raw, cleaned tooth using x1k magnification. It shows that the surface texture of the tooth is not very uniform. This actually represents the structure of the enamel surface of the tooth. The raw tooth image was captured prior to the process of applying an adhesive material. Fig. 1b shows the surface morphology of the tooth sample with an adhesive material. From the figure, it shows an image like bubbles on the tooth surface. This condition indicates the uneven surface of the adhesive material applied to the tooth and the non-uniformity of the tooth surface texture. In particular, the results of applying adhesives may vary according to the process. It is very challenging to produce a consistent thickness of adhesive material throughout the tooth sample. Therefore, the non-uniformity of the surface is due to the inconsistent thickness of the adhesive material throughout the tooth surface.

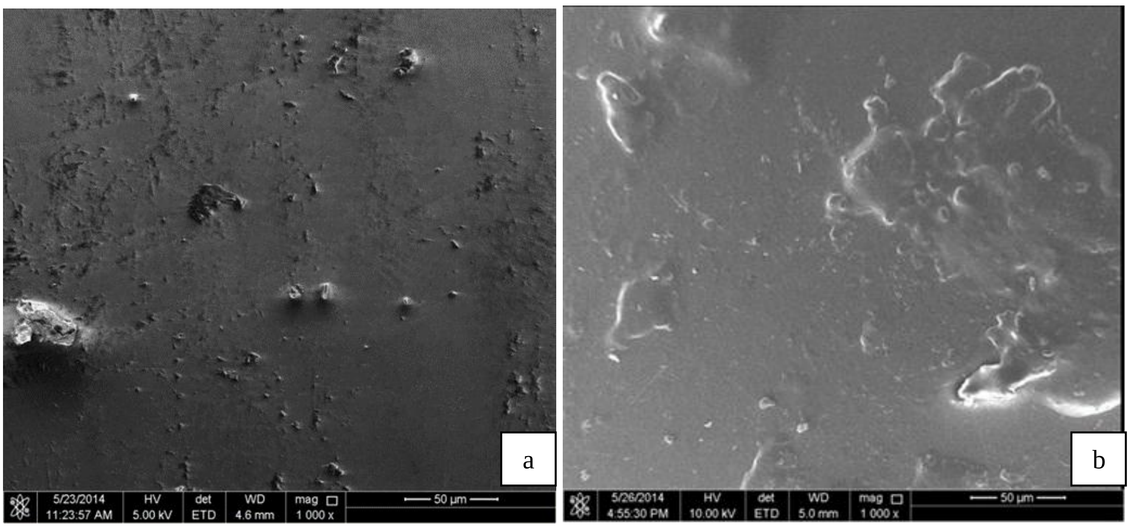

Fig. 1 : Surface morphology using x1k magnification. a) Raw tooth. b) Adhesive material applied on the surface of the raw tooth.

Table 1 shows the elemental composition obtained for the raw tooth, which is without adhesive material. The element consists of Carbon (C), Silicon (Si), Calcium (Ca), Phosphorus (P), and Oxygen (O). Carbon has the highest weighting percentage (28.83%) as well as atomic percentage (44.72%) while the lowest wt% and at. % element is Si (2.94% and 1.95%). Referring to Table 2, only three elements are identified. The most abundance element is carbon with 53.66% of wt.% and 60.76% of at.%. Next, the oxygen (45.98% of wt.% and 39.08% of at.%) and phosphorus elements (0.16% of wt.% and 0.16% of at.%). Due to inherent changes in morphology and composition of teeth from human to human and from one tooth to another tooth, a true quantitative analysis is virtually impossible [7]. It is because, dental samples are not always flat and free of surface defects. Besides that, a reference standard for each type of sample use in not known. In this experiment, the EDX elemental analysis highlighted the presence of Phosphorus, Calcium, Silicon, Carbon and Oxygen. According to Table 2, the weighted percentage of oxygen is highest compared to phosphorus and calcium. The larger wt.% number of oxygen is probably due to the bleaching process indicating the amount of calcium and phosphorus loss from the enamel surface. Bleaching will cause significantly decrease in Ca/P ratio as compared with no bleaching procedure in tooth preparation [8]. The decreasing in bond strength can be overcome by applying a biocompatible and natural antioxidant such as sodium ascorbate before resin composite application.

Table 1: Elemental composition by at. % and wt. % of each element that had been identified for raw teeth.

Element	*at. %*	*wt. %*	*wt. sigma %*
O	33.38	28.66	1.13
P	6.83	11.35	0.62
Ca	13.12	28.22	1.06
Si	1.95	2.94	0.33
C	44.72	28.83	1.18
Total	100	100	-

Table 2: Elemental composition by at.% and wt.% of each element that had been identified for teeth with adhesive material.

Element	*at.%*	*wt.%*	*wt. sigma %*
O	39.08	45.98	1.76
P	0.16	0.36	0.27
C	60.76	53.66	1.76
Total	100	100	-

3.2. Fluence Energy Effect

Fig. 2a, 2b, 3a and 3b show the surface morphology of the tooth sample after irradiation with different fluence energy. Table 3, 4, 5 and 6 show the elemental composition of the tooth sample with various fluence energy after irradiation. Fig. 2a and Table 3 show the surface morphology and elemental composition for energy fluence of 100J/cm^2,respectively. From the image with 1000x magnification, it shows that the smooth surface morphology with a small area containing bubbles. These bubbles is due to the non-uniform surface texture based on the area captured for analysis. Fig. 2b and Table 4 show the surface morphology and elemental composition of teeth sample for energy fluence of 200J/cm^2,respectively. This selected fluence with x1000 magnification shows an image with smooth surface morphology without any bubble area. Similarly, Fig. 3a and Table 5 show the surface morphology and elemental composition of a tooth sample irradiated with 250J/cm^2, respectively. Referring to the image, it shows a large area of non-uniformity of surface texture. Fig. 3b and Table 6 show the surface morphology and elemental composition of teeth sample with 300J/cm^2 energy fluence, respectively. Image shows a grain amorphous surface with a holes throughout the sample surface.

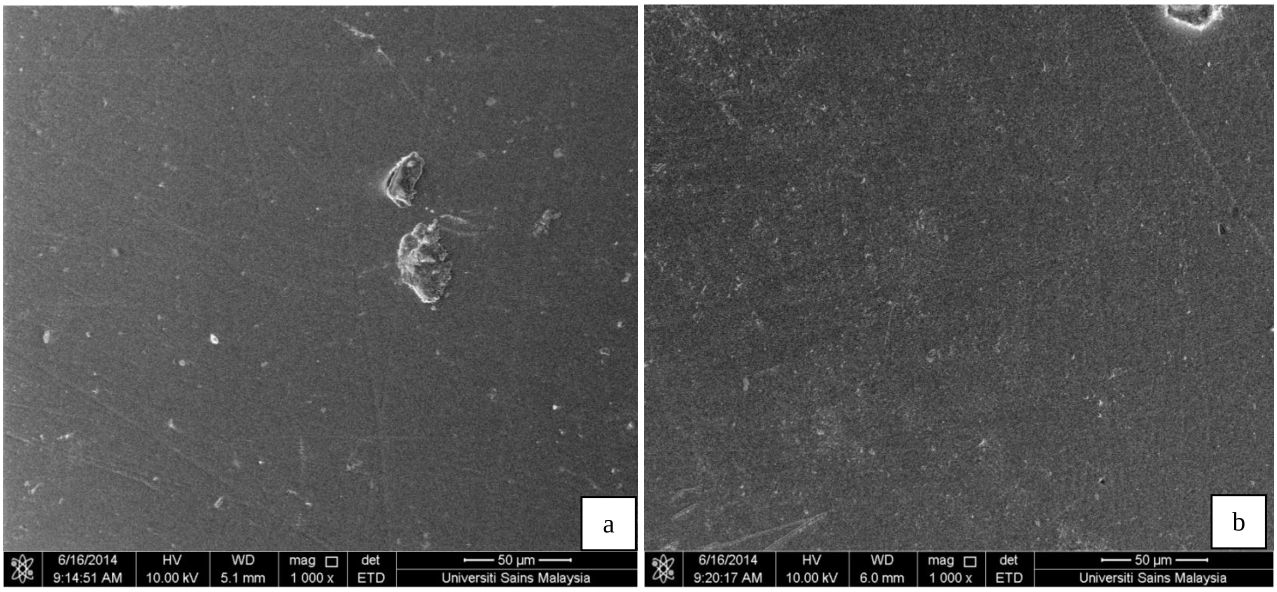

Fig. 2: Surface morphology. a) PW 200ms, PR 1.5Hz, BS 3mm and fluence energy of 100J/cm^2. b) PW 200ms, PR 1.5Hz, BS 3mm and fluence energy of 200J/cm^2

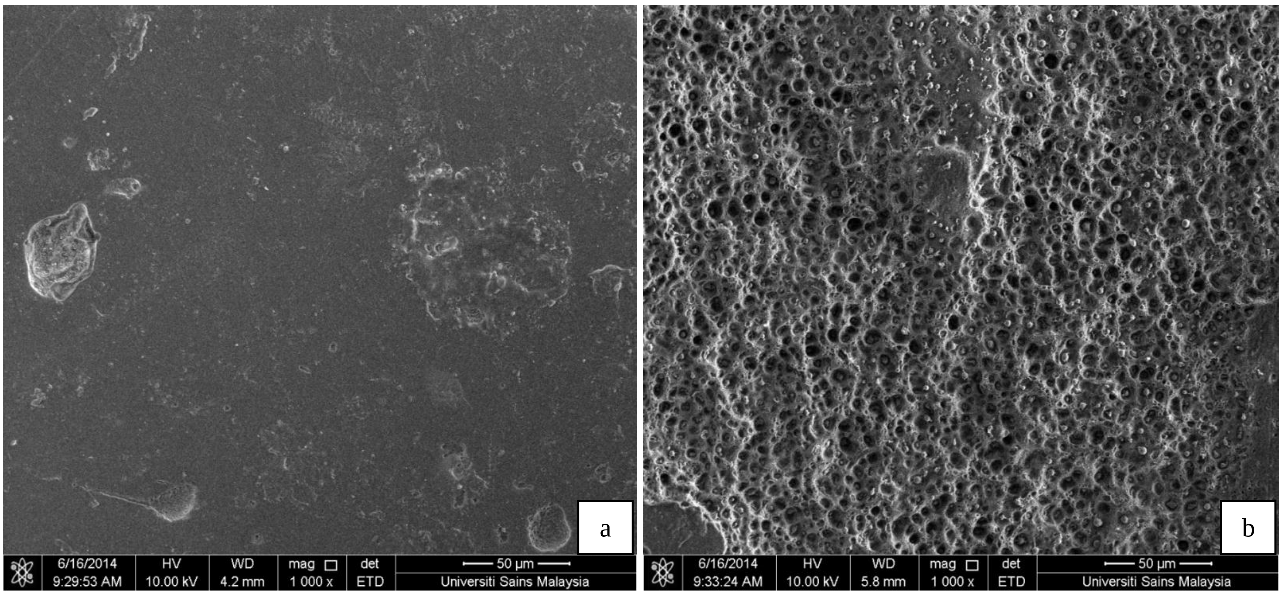

Fig. 3: Surface morphology. a) PW 200ms, PR 1.5Hz, BS 3mm and fluence energy of 250J/cm^2. b) PW 200ms, PR 1.5Hz, BS 3mm and fluence energy of 300J/cm^2.

According to Table 3, it is shown that the highest elemental composition for tooth with energy fluence 100J/cm^2 is carbon. It is according to its wt% as well as at.%. carbon have 51.23% of wt% and 59.19% for at.%. The least composition is phosphorus with 3.57% of wt.% and 1.60 of at.%. As shown in Table 4, EDX measurement indicates result for three compositions of elements which are carbon, oxygen and phosphorus in decreasing order. Carbon has the highest abundance with 53.21% for wt. % and 60.68% for at. %. The lowest abundance of elemental composition of this sample is phosphorus. The amount of wt. % of phosphorus is 1.81% and 0.80% of at.%.Referring to Table 5 for EDX analysis of energy fluence 250J/cm2, carbon is the most abundance elemental composition compared to oxygen and phosphorus. Phosphorus has the lowest percentage for both at.% and wt.% with 4.65% of wt.% while carbon is 51.90% of wt.% while for at.% of carbon is 60.12% and phosphorus is 2.09%. Table 6 shows the elemental composition for irradiated tooth sample with fluence energy 300J/cm^2. From the table, it shows that, carbon has the most abundance element in the tooth sample with 53.91% of wt.% and 62.77% of at.% while the lowest abundance element is phosphorus with 7.25% of wt.% and 3.27% of at.%. There are altogether three elements that had been identified for this sample.

Table 3: Elemental composition by at. % and wt. % of each element that had been identified for irradiated teeth with PW 200ms, PR 1.5Hz, BS 3mm and fluence energy 100J/cm^2.

Element	*at.%*	*wt.%*	*wt. sigma %*
O	39.21	45.20	1.43
P	1.60	3.57	0.51
C	59.19	51.23	1.43
Total	100	100	-

Table 4: Elemental composition by at. % and wt. % of each element that had been identified for irradiated teeth with PW 200ms, PR 1.5Hz, BS 3mm and fluence energy 200J/cm^2.

Element	*at.%*	*wt.%*	*wt. sigma %*
O	38.51	44.98	1.27
P	0.80	1.81	0.32
C	60.68	53.21	1.27
Total	100	100	-

Table 5: Elemental composition by at. % and wt. % of each element that had been identified for irradiated teeth with PW 200ms, PR 1.5Hz, BS 3mm and fluence energy 250J/cm^2.

Element	*at.%*	*wt.%*	*wt. sigma %*
O	37.79	43.45	1.12
P	2.09	4.65	0.42
C	60.12	51.90	1.13
Total	100	100	-

Table 6: Elemental composition by at. % and wt. % of each element that had been identified for irradiated teeth with PW 200ms, PR 1.5Hz, BS 3mm and fluence energy 300J/cm^2.

Element	*at.%*	*wt.%*	*wt. sigma %*
O	33.96	38.86	1.18
P	3.27	7.25	0.55
C	62.77	53.91	1,21
Total	100	100	-

Irradiation of dental hard tissue with laser such as Nd:YAG laser of sufficient power will lead to a variety of structural and ultra-structural changes of their tissue near the surface [9]. These changes depend on several irradiation parameters such as wavelength, pulse duration, pulse energy and beam spot size. Ablation by laser means to remove material from a substrate by direct absorption of laser energy. In this study, four types of energy fluence were used which are 100J cm^{-2}, 200J cm^{-2}, 250J cm^{-2}, and 300J cm^{-2}. At low fluence, photothermal mechanism for ablation occurs. It includes material evaporation and sublimation. If the adhesive is more volatile species, it may be depleted more rapidly. Besides that, it also changes the chemical composition of the remaining material. Using high fluence, heterogeneous nucleation of vapor bubbles may occurs and will lead to normal boiling. If the adhesive material was heat sufficiently the adhesive will approach thermodynamic critical temperature, rapid homogeneous nucleation and expansion of vapor bubbles that lead to explosive boiling then carry off the adhesive fragment [10].

The experimental data obtained using EDX for teeth enamel after irradiation with various energy fluence with respect to at.% and wt% are Ca, P and O as presented in Table 3, Table 4 Table 5 and Table 6. The at.% and wt.% of O decrease with increasing energy fluence. There was no Ca compound found after laser irradiation result. The confinement of deposited energy to desired regions of a tooth surface can cause heating. Although the advantage of the laser has an ability to precisely control specific area in the tooth and rate of energy deposited, the excess irradiation may leads to burn.

After laser irradiation at 100J/cm^2 energy fluence, the wt% of C was reduced to 59.19% . It means that some of the adhesive layer was removed from the enamel surface. At 200J/cm^2 the wt% of C increase drastically to 53.21%. Based on ablation methodologies, the absorption process occurs on the adhesive make the adhesive become more carbonize. When 250J/cm^2 energy fluence was applied, again the wt% of carbon was reduced, but when energy fluence of 300J/cm^2 was applied, the amount of wt% C increased again. This potentially because the adhesive layer absorbs the energy and the ablation process occur, and thus remove the adhesive material.

Base on literature understanding, it is also assumed that lower boiling point for components of hard tissue such as water, collagen and proteins, will quickly vaporized by heating [9]. The rapidly expand and vapor processes, remove the mineral component. Additionally, the bond strength of adhesive material should be sufficient enough to withstand orthodontic and functional forces, but it must have an appropriate level to allow the process of bracket deboning without causing damage to enamel [10]. The ablation threshold for enamel using Nd:YAG with 1Hz laser was 300J cm^{-2} and the multiples irradiation does not cause the rater formation. Finally, the ablation threshold for all the dental material are significantly lower than the threshold fluences for the dental tissue (enamel) but greater than 30J cm^{-2} [11].

4. Conclusion

Tooth enamel is the most mineralized tissue of the human body that composed of 96wt. % inorganic material and 4wt. % of organic material and water [12]. In this experiment, x-ray energy dispersive spectroscopy (EDX) analysis of enamel indicates elements of oxygen, phosphorus, calcium, silicon, and carbon. The smallest quantity of an element in enamel is Si. The experimental result makes it possible to determine the main features of the ablation of adhesive materials using milliseconds pulses Nd:YAG laser. Due to the thickness of transbond plus self-etching primer applied and high pulse Nd:YAG laser, the effective ablation was between 250-300J cm^{-2} ,which also avoid the ablation of the enamel. There were several procedures that remain unchanged in modern dentistry. The application of laser ablation technique to remove adhesive materials on enamel provides a decrease in various dental manipulations and it will make the manipulation become easy. Thus, the quality of treatment becomes higher and this laser ablation technique is more promising for practical dentistry. This research study provides the proof of concept of the adhesive removal process which can be achieved using Cynosure Cynergy Nd: YAG laser.

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