THE EFFECT OF ND:YAG LASER ON ENAMEL SURFACE AND COMPOSITION FOR REMOVAL OF COMPOSITE ADHESIVES

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UNIVERSITI SAINS MALAYSIA

2018

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by

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Thesis submitted in fulfillment of the requirements for the degree of Master of Science (Dentistry)

October 2018

ACKNOWLEDGEMENT

With the name of Allah,
The Most Gracious, The Most Merciful.

I would like to thank all those people who made this thesis possible and unforgettable experience for me. First of all, I wish to express my sincere gratitude to my main supervisor, Dr. Fatanah Mohamad Suhaimi for all her guidance, advice and knowledge and also criticism in guiding me through the project. I also would like to thank my co-supervisor, Dr. Norehan Mokhtar for her idea, guidance and knowledge. Next, I also wish to acknowledge all the staffs of Craniofacial and Biomaterial Sciences Cluster of Advanced Medical and Dental Institute (AMDI), Universiti Sains Malaysia, especially the science officers, Ms. Nur Syazana, Mrs. Nurulakma Zali and other staffs for always give their best in assisting me and other postgraduate students here.

Finally, I would like to express my deepest gratitude for an endless moral support, emotional understanding and true love that I got from my beloved parents and the whole family and the blessings of Allah to complete my study successfully. Thank you very much.

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LIST OF SYMBOLS AND UNITS

J	Joule
mJ	milliJoule
mm	millimeter
nm	nanometer
µm	micrometer
cm	centimeter
cm^2	centimeter squared
J/cm^2	Joule per centimeter squared
s	seconds
ms	milliseconds
µs	microseconds
V	Volt
E	Energy
rpm	rotation per minute
%	Percent
E^{thr}	Energy threshold
Hz	Hertz
mag.	magnification

LIST OF ABBREVIATIONS

FESEM	Field Emission Scanning Electron Microscopy
EDX	Energy Dispersive X-Ray
Nd:YAG	Neodymium: yttrium, aluminium, garnet
Er,Cr:YSGG	Erbium, chromium: yttrium, scandium, gallium, garnet
Er:YAG	Erbium: yttrium, aluminium, garnet
KTP	Potassium titanyl phosphate
CO_2	Carbon dioxide
LED	Light emitting diode
CEJ	Cementoenamel junction
DEJ	Dentinoenamel junction
AFM	Atomic force microscopy
INOR	Institute of Nano Optoelectronics Research and Technology
SMMRE	School of Materials and Mineral Resources Engineering
AMDI	Advanced Medical and Dental Institute
ISI-SIR	Ibnu Sina Institute for Scientific & Industrial Research
CA	California
USA	United States of America
MA	Massachussetts
UK	United Kingdom
CI	Confidence Interval

KESAN LASER ND:YAG PADA PERMUKAAN DAN KOMPOSISI ENAMEL BAGI PENYINGKIRAN PELEKAT KOMPOSIT

ABSTRAK

Penyinaran laser Nd:YAG (1064 nm) ke atas permukaan enamel dan penyingkiran pelekat komposit telah dikaji. Analisis mikroskopi elektron pengimbas (FESEM) dan sinar-x tenaga serakan (EDX) digunakan untuk memerhatikan perubahan morfologi permukaan dan komposisi elemen pada permukaan gigi. Karbon, oksigen, fosforus dan kalsium adalah elemen-elemen yang dikenalpasti dalam sampel. Dalam kajian ini, kesan parameter laser Nd:YAG seperti fluens, lebar denyut dan tenaga telah dikaji. Empat puluh premolar yang sihat dipotong kepada dua bahagian untuk penyinaran laser Nd:YAG. Kajian ini dibahagikan kepada dua kategori iaitu penyinaran laser tanpa pelekat dan dengan pelekat. 45 sampel dikelaskan secara rawak untuk sampel tanpa pelekat, manakala 35 sampel digunakan dengan pelekat. Kesan penggunaan pelbagai tetapan seperti fluens, lebar denyut dan tenaga juga dibincangkan. Variasi fluens dan lebar denyut digunakan pada sampel tanpa pelekat, manakala variasi tenaga dikenakan pada sampel dengan pelekat. Fluens 120 J/cm^2 dan lebar denyut 150-200 ms adalah rangkaian parameter yang sesuai dimana kurang kerosakan dihasilkan pada permukaan kawasan enamel yang telah disinari. Selepas penyinaran laser, tahap komposisi karbon dalam EDX meningkat, manakala oksigen berkurang. Untuk menyingkirkan pelekat komposit, 540 mJ memadai untuk proses penyingkiran komposit, dimana ia menghasilkan permukaan berbentuk bijian bertaburan dan kurang lekapan. Keputusan EDX menunjukkan penurunan peratusan karbon, namun berlaku peningkatan dalam peratusan oksigen. Kajian ini menyimpulkan bahawa kesan sinaran laser Nd:YAG ke atas permukaan enamel dan bahan pergigian adalah berbeza bergantung kepada

parameter yang digunakan semasa proses penyinaran laser dan pelekat pada permukaan gigi.

THE EFFECT OF ND:YAG LASER ON ENAMEL SURFACE AND COMPOSITION FOR REMOVAL OF COMPOSITE ADHESIVES

ABSTRACT

Nd:YAG laser (1064 nm) irradiation on enamel surface and removal of composite adhesives was studied. Field Emission Electron Microscopy (FESEM) and Energy Dispersive X-Ray (EDX) analysis were used to observe the changes in surface morphology and composition of elements on the tooth surface. Carbon, oxygen, phosphorus, and calcium were the elements identified in the samples. In this study, the effect of Nd:YAG laser parameter such as fluence, pulse width and energy were investigated. Forty healthy premolars were cut into half and subjected to Nd:YAG laser irradiation. The study was divided into two categories which were laser irradiation without adhesives and laser irradiation with adhesives. 45 samples were randomly classified into without adhesives application whereas 35 samples were applied with adhesives. The effects of using multiple settings of fluence, pulse width and energy were also discussed. Fluence and pulse width variation were used on samples without adhesive, while energy variation was tested on the samples with adhesives. 120 J/cm^2 of fluence and 150-200 ms of pulse width were the best range of parameters where less damage was produced to the irradiated area of the enamel surface. After laser irradiation, the level of carbon composition increased in EDX, while the oxygen element decreased. For removal of composite adhesives, 540 mJ seems to be adequate for the removal and shows less indentations and a scattered graininess on the tooth surface. EDX results shown reduction in carbon percentage, but increased in oxygen percentage. This study concludes that the effect of Nd:YAG laser irradiation on enamel surface and dental

material would be different depends on the parameters used during irradiation and adhesives conditioning on the tooth surface.

CHAPTER 1

INTRODUCTION

1.1 Background

Over the past few years, dentistry field has received growing interest and advancement. Orthodontic procedures often involve the use of two main components, which are brackets and wires. Adhesive dental materials are also used in the procedures. The adhesive dental material is a form of a substance that creates bonding or adhesion between the dental braces and underlying tooth substance. Dental braces in orthodontic treatments aimed to align, straighten and correct malocclusions such as underbites, overbites, cross bites and so forth. There are several types of orthodontic braces available in the market, which are metal braces, clear plastics or ceramic braces and ceramic tooth coloured braces. After brackets bonding process, the brackets will be debonded from the tooth surface leaving the residual dental material on the enamel surfaces.

Earlier studies by Alexander et al. (2002) discussed on the selective ablation of the remaining composite by using Q-switched Nd:YAG laser from enamel surfaces. Another study by Siniaeva et al. (2009) studied on the removal of dental material by a microsecond Nd:YAG laser. Both studies yield positive results on the application of Nd:YAG laser without causing any discernable damage to the underlying enamel. Hence, this study is designed to investigate the effect of using various kinds of Nd:YAG laser parameters on tooth structure and composite adhesives. The results would be different because the enamel structure has its own composition, as well as composite adhesives. This is how important to find the safe laser parameter which did not affect the enamel surface and give positive results towards removing the unwanted adhesive. The irregular surfaces of enamel also contribute to the difficulties in achieving complete ablation. This is because when the enamel surface is not similar from one sample to another, the penetration level of laser irradiation onto the enamel surface might be different depending on the intensity of the laser used. Hence, the effect of laser irradiation on enamel might be different between samples.

1.2 Research problem

The removal of adhesive dental material usually involves conventional techniques which potentially cause damage to the surface of the tooth. Until today, orthodontists used mechanical approaches such as carbide burs and polishing cups to remove the material. This method has been widely accepted and clinically adapted even though it might cause severe damage to the surface of the teeth (Alexander et al., 2002). Therefore, laser as an alternative can be used to ablate the residual material and thus remove it from the enamel surface. However, selecting proper laser parameter is very crucial to avoid any microstructural damage on the surface of the tooth. Often, after laser irradiation, the enamel will undergo relatively small physical changes such as melting and recrystallisation, resulting in the formation of bubble-like structures and numerous pores. Thus, it is important to choose the optimum laser parameter specifically for removing adhesive dental materials. Besides, the reactions of composite adhesive towards different laser setting should also be considered.

1.3 Objectives of the study

The main objective of the study is to optimize the effect of Nd:YAG laser on enamel surface and composition following the removal of composite adhesives. In attempt to achieve this objective, the following tasks are accomplished:

a) To determine the effect of fluence and energy Nd:YAG laser on the enamel surface.

b) To characterize the changes of surface morphology and elemental composition on enamel surface following Nd:YAG laser removal of composite adhesives.

c) To optimize the pulse width effect on to the enamel surface.

1.4 Scope of the study

This study was conducted in the Advanced Medical and Dental Institute (AMDI), Universiti Sains Malaysia. The materials used in this study are healthy premolar teeth samples, which were taken from patients in AMDI clinics and nearest dental clinics around Bertam, Penang. Various parameters of Nd:YAG laser was applied such as fluence, pulse width and energy. Fluence parameters of 90 J/cm^2, 100 J/cm^2, 110 J/cm^2 and 120 J/cm^2, whereas pulse width varied from 150 ms, 200 ms, 250 ms and 300 ms were used in this study. The ranges of energy started from 500 mJ to 580 mJ. Nd:YAG laser was used to irradiate directly on enamel surface and the remaining composite material on enamel after bracket debonding process. The range of distance between enamel surfaces to the laser system is 3.0 cm and the spot diameter is 3.0 mm. Analysis of Field Emission Scanning Electron Microscopy (FESEM) and Energy Dispersive X-Ray (EDX) were conducted for each sample before and after laser irradiation. FESEM analysis functions to observe morphological changes of the sample, while EDX analyses the elemental composition found in the desired area of the sample.

1.5 Significant of the study

The results from this study would be useful to be applied in the dentistry field, especially in orthodontic treatment. With the use of a laser, the efficiency to remove composite materials after bracket debonding process would be improved, rather than the use of conventional methods which causes a significant thermal effect to the enamel. The application of laser with appropriate parameter settings is more practical and beneficial to the orthodontists as it will not cause harm to the structure of the teeth while giving full comfort to the patient. Besides, the treatment can also be done in a shorter time frame.

1.6 Outline of the thesis

Thisthesis is organized as the following: Chapter 2 reviews the previous study on the application of Nd:YAG laser in the dental field for laser ablation on enamel surface and composite removal with various laser parameters.

Chapter 3 presents the materials and methodology involved in this study. The chapter is divided into several subtopics include sample preparation, material bonding and debonding procedure, laser irradiation and sample analysation.

Chapter 4 discusses the surface morphology analysis using FESEM and elemental composition analysis using EDX. The elemental compositions are representedin terms of weight percentage and atomic percentage. The effect of various laser parameters (fluence, pulse width and energy) on the tooth surface and material after laser irradiation also discussed.

Chapter 5 concludes the best ranges of laser parameters obtained for laser irradiation on enamel surface and laser irradiation on composite adhesives and method to achieve effective laser ablation.

CHAPTER 2

LITERATURE REVIEW

2.1 Structure and composition of a tooth

Teeth are the hardest substances in the human body. The primary function of the teeth is to chew and mechanically break down foods and nutrients. Besides, the teeth play very important roles in speech. Figure 2.1 shows the complete structure of a tooth. Incisors, canines, premolars and molars are four categories of teeth that have their properties and functions. Incisors are the teeth that play a role to bite food. The sharpest teeth, canines, are responsible for tearing and ripping food apart. While, premolars (also known as bicuspids) and molars, both are for chewing and grinding foods into small pieces.

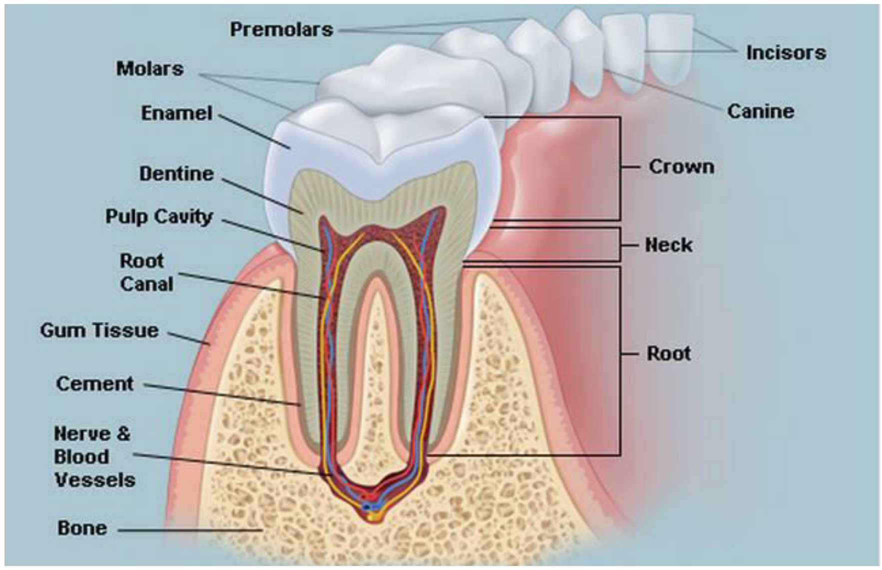

Figure 2.1 Structure of a tooth (Adapted from Matthew, 2015)

The tooth is divided into crown and root. The crown (clinically visible) contains enamel, dentin, pulp. The root is enclosed within the alveolar bone and supported by supporting tissues such as periodontal ligament, gingival, pulp and cementum. Enamel is the most highly mineralised tissue and the hardest part of the body. Enamel consists of organic and inorganic substances. It is the outer part of the teeth and it is supported by an underlying dentin. Enamel rod is a cylindrical and basic structural unit of enamel with a highly organised pattern of hydroxyapatite crystals (Mary & Margaret, 2006). The enamel composed of millions of enamel rod or prism covered by rod sheaths and cementing inter rod substances. The inorganic substances concentration is about 96% and the rest 4% is organic substance (Teruel et al., 2015). The inorganic material is present in the form of hydroxyapatite, for instance, crystalline calcium phosphate. The chemical nature of organic substance has not been completely determined, but it is largely proteinaceous and contains some polysaccharides (Nanci, 2003). Figure 2.2 shows the morphological structure of enamel.

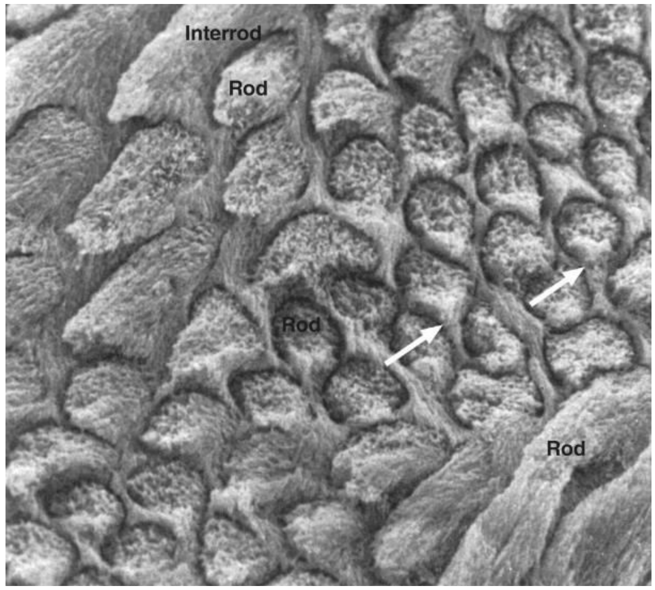

Figure 2.2 Morphological structure of enamel (Accessed from Arthur, 2015)

Dentin is one of the main components of the teeth. It is a hard calcified tissue that lies together with enamel, cementum and dental pulp within the clinical crown of a tooth. Dentin varies in different types such as peritubular dentin, intertubular dentin, predentin, primary dentin, secondary dentin, tertiary dentin, interglobular dentin and sclerotic dentin. Dentin is secreted by the odontoblasts of the dental pulp. The chemical composition of dentin is 70% inorganic materials, 20% organic materials, and 10% water (Nanci, 2013). When the dentin is viewed under a microscope, several structural features can be identified. These include the dentinal tubules, intra and inter tubular dentin as shown in Figure 2.3. The structure of dentin is softer than enamel. Apart from that, it is more likely to undergo rapid decay compared to enamel and easy to get infected by cavities if not properly treated.

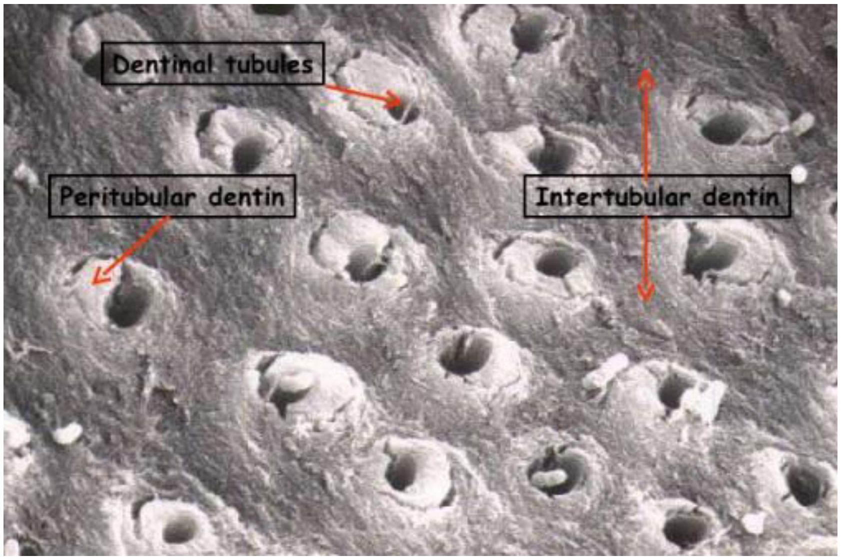

Figure 2.3 Morphological structure of dentin (Adapted from Nanci, 2003)

Cementum is also one of the important parts of the teeth. It is a connective tissue which contains minerals and functions to cover the dental pulp of teeth at the root area. It also acts as an anchorage of teeth to the adjacent alveolar bone *via* the periodontal ligament. The roots and crowns of teeth are two locations where cementum can be found. The cementum that is found on the surfaces of roots is called radicular cementum, while coronal cementum is the cementum that forms enamel which covers the crown. It resembles bone-like-structures, but it is non-vascular and undergoes slow growing throughout life. There are various structures and forms of cementum includes cellular structures, fibrillar collagenous matrix and non-cellular cementum (Tziafas, 2005).

2.2 Orthodontic brackets

One of the important parts of fixed appliances in orthodontic procedure is orthodontic brackets. The first application of orthodontic brackets was found since prehistoric era, which is about 3000 years ago to correct crowded teeth on Greek, Etruscan and Egyptian artifacts (Matasa, 2003). A French dentist, Pierre Fauchard was the first one to make attempt to align teeth by a device called Bandeau, which made of precious metal and horseshoe-shaped and helped expand the arch (Khan, 2015). His work was then published in a landmark book entitled *The Surgeon Dentist: A Treatise on the Teeth* in 1728. Further clinical researches on orthodontic brackets and advancement in orthodontic bonding were done by other dentists by years.

These brackets function to align, straighten and correct malocclusions by temporarily attached to the teeth surface together with the help of the forces from the wires. Various types of orthodontic brackets available in the market and comes with different kind of materials, which are metals, ceramics, plastics or combination materials. Metallic orthodontic brackets have demonstrated properties that are closer to the ideal and the most common bracket used by orthodontists in clinical treatment (Bazakidou et al., 1997). Besides, metal brackets also have good corrosion resistance and good biocompatibility (Keun-Taek, 2005). Hence, metal brackets were chosen to be used in this study due to its advantages in orthodontic treatment.

2.3 Adhesive composite

In fixed appliances, the wires are aligned through the brackets on the teeth with the help of bonding agents called adhesive composites. These composites functioned to bond one substrate to the other and formed two interfaces, which are between the adhesive and the substrates (Marshall et al., 2010). The substrates in terms of dental perspective refer to dental composite resin, enamel, dentin, veneer or orthodontic bracket (Özcan et al., 2012). Hence, enamel and orthodontic bracket are two substrates that are used in this study.

The adhesion of enamel and dentin would create different problems, as they both have different compositions and anatomies. The adhesion of material onto the enamel requires a form of mechanical retention because enamel's anatomy is harder than dentin (Nicholson, 1998). The dentin, otherwise, does not require any retention in bonding procedure. Buonocore (1955) introduced the acid-etch technique by roughened the enamel surface with an acidic etchant, for instance, 37% viscous gel of phosphoric acid. Through this process, chalky surface appeared, and microporosity increased in order to ease the attachment of adhesive composite to the enamel. The bonding between enamel and orthodontic bracket via adhesive composite may also cause side effects to the patient after treatment such as minimizing the risk of leakage, recurrent caries and post-operative sensitivity (Van Meerbeek et al., 2003). Various outcomes occur after adhesion took place is undoubtedly due to the properties of the tooth and the material itself.

2.4 Laser and its properties

Laser irradiation has been proposed as a new alternative in modern technology to decrease the level of discomforts to the patients, concerning pressure, vibration and noise during cavity preparation (Kumazaki, 1998). Laser is an abbreviation for light amplification by the stimulated emission of radiation. Laser light is monochromatic since it produces a single color beam, which is invisible when its wavelength is outside of the visible part of the spectrum (Coluzzi, 2015). Laser is also coherent, or has similar physical size and shape. Some instruments emit all laser beams parallel to each other (collimate) over a long distance. However, for the optical fibre; for example, Nd:YAG and diode lasers, the beams of both lasers usually diverge at the fibre tip.

The laser produces light waves in the form of electromagnetic energy. The range of wave energy varies from gamma rays, with a wavelength of $10\text{-}10^{-12}$ m to radio waves, with a wavelength of thousands of meters. Dental lasers emit either visible light or infrared light wavelength called thermal radiation (Everett, et al., 1998). Argon laser, KTP (potassium titanyl phosphate) laser and low-level laser are the examples of dental lasers that emits visible light, while infrared light wavelength is emitted by diode lasers (800-1064 nm), Nd:YAG laser (1064 nm), Er,Cr:YSGG laser (2780 nm), Er:YAG laser (2940 nm) and CO_2 laser (10,600 nm). Figure 2.4 shows various dental lasers with their corresponding wavelengths.

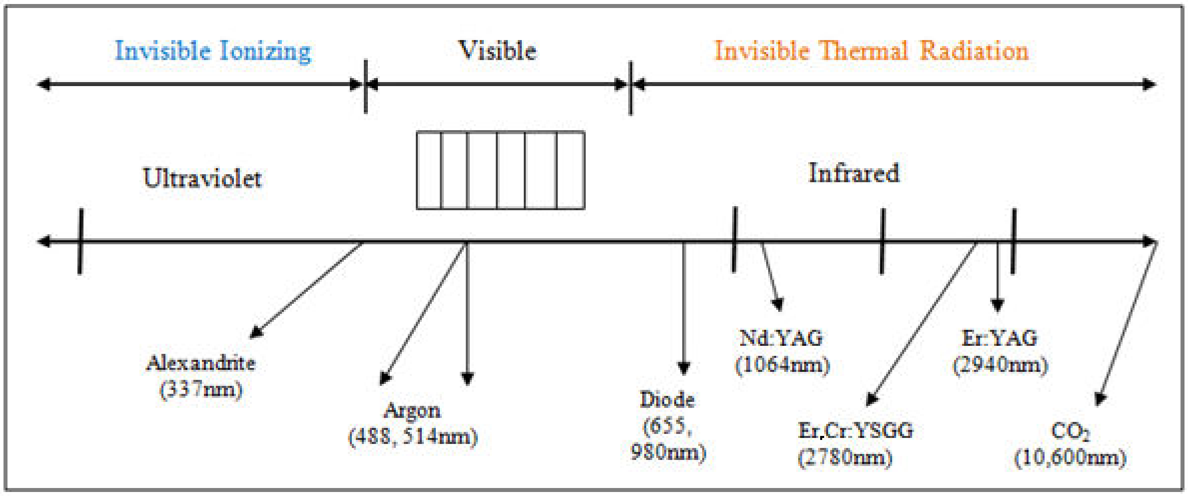

Figure 2.4 Various dental laser wavelengths on electromagnetic spectrum (Adapted from Coluzzi, 2004)

Laser is a device capable of producing an intense beam of coherent and monochromatic light by stimulated emission of the photons from excited atoms or molecules. It is a process of oscillating hence amplifying stimulated emission that makes the laser light unique. Hence, the abbreviation of laser has simplified the whole physical process of the production of light. The laser is an energy transformer. It transforms different kinds of energy such as kinetic of electrical energy and light energy into new types of optical energy.

2.5 Laser in dentistry

The laser is a type of non-ionising radiation and has been applied in the medical and dentistry field. It was used for many applications for soft and hard tissues in dental treatment. In soft tissue application, the laser was used to remove or surgically remove tissues for gingival hyperplasia, benign and malignant lesions (along with conventional surgery), intraoral soft tissue surgery (ablating, incising, excising, coagulating), and red-white lesions (Viraparia et al., 2012). Besides, the removal of coronal pulp and pulpotomy (adjuncts to root canal procedures) also among the examples of soft tissue laser applications. As for the application on hard tissue, laser works in cavity preparation, etching, photochemical effects, caries detection and removal, laser fluorescence, growth modulation and for diagnostic purposes. The laser also has been used in miscellaneous applications such as nerve repair and regeneration, post surgical pain and analgesic effect of the laser (Verma et al., 2012). Lasers are also used in endodontic orifice location, dental caries diagnosis, measurements of blood flow and illumination of caries detection.

Various types of dental laser are available which are widely used in dental practice such as carbon dioxide (CO_2) laser, neodymium-doped yttrium aluminium garnet (Nd:YAG) laser, erbium laser; erbium-doped yttrium aluminium garnet (Er:YAG) laser and erbium, chromium: yttrium scandium gallium garnet (Er,Cr:YSGG) laser (Wadhwani, 2007). Lasers can be classified based on its light spectrum, the lasing medium used, tissue applicability and wavelengths. The lasing medium can be either gas, solid, or liquid. The main instances for tissue applicability are hard and soft tissue lasers. CO_2 laser and Nd:YAG laser are the examples of hard tissue lasers, diode laser is a type of soft tissue laser, while both erbium lasers, Er:YAG and Er,Cr:YSGG lasers have the ability to cut efficiently for both soft and hard tissues (Walsh, 2003). The range of possible wavelengths depends on the laser material and the optical design of the laser. Table 2.1 shows various kinds of common lasers used in dentistry. The use of dental laser provides advantages to both orthodontists and patient due to their effectiveness in cutting, cleaning hard tissue cuts, able to reduce pain as well as produce low noise and vibration during treatment (El Naga et al., 2012).

Table 2.1 Common laser types used in dentistry (Adapted from Verma et al., 2012)

Laser Type	Construction	Wavelength (s)	Delivery system (s)
Argon	Gas state	488, 515 nm	Optical fibre
KTP	Solid state	532 nm	Optical fibre
Helium-neon	Gas state	633 nm	Optical fibre
Diode	Semiconductor	635, 670, 810, 830, 980 nm	Optical fibre
Nd:YAG	Solid state	1064 nm	Optical fibre
Er,Cr:YSGG	Solid state	2780 nm	Optical fibre
Er:YAG	Solid state	2940 nm	Optical fibre, waveguide, articulated arm
CO_2	Gas state	9600, 10600 nm	Waveguide, articulated arm

2.6 History and development of laser in dentistry field

Traditional dental procedure involves the use of carbide burs or polishing cups to drill or cut soft and hard tissues. The first application of laser in dentistry was introduced by the American physicist Maiman at the Hughes Research Laboratories, in 1960, where the working laser was built by using a synthetic ruby crystal made of aluminium oxide and chromium oxide (Maiman, 1960). Since those early years, synthetic ruby was the only material that regularly used as an active medium in lasers. The majority of researchers applied that ruby laser, which emits light of 0.694 µm wavelength to study tissue interaction with enamel and dentin (Ballal et al., 2011).

A year later, Snitzer released the second laser called neodymium in glass (Snitzer, 1961) and later Johnson and Nassen developed the first solid state Neodymium laser (Johnson, 1961). Carbon dioxide (CO_2) laser was made a history of the first laser to be marketed for general intraoral use and has been applied for tissue surgery. The year 1990's saw the Food and Drug Administration (FDA) clearance for Nd:YAG laser's intraoral use, which is developed by Myers & Myers and the laser was known as the first laser designed specifically for general dentistry (Pohlhaus, 2012). Since then, the science of laser has progressed drastically by years, and many studies regarding the application of dental laser involving the soft and hard tissue applications were carried out by researchers and practitioners.

Based on official website of U.S Food and Drug Administration (FDA), laser products that are used for medical applications must comply with the medical device regulations. There are laws, regulations and standards to be complied by medical lasers to avoid injury from biological hazards caused by each laser class used. The safe laser wavelength permissible on hard tissues ranged from 488 nm to 10600 nm. The manufacturers of radiation emitting products are responsible for compliance with the

Federal Food, Drug and Cosmetic Art (FFDCA), Chapter V, Subchapter C- Electric Product Radiation Control. Laser products must comply with all applicable requirements of Title 21 Code of Federal Regulations (Subchapter J, Radiological Health) Parts 1000 through 1005. In addition, manufacturers of laser products must comply with radiation safety performance standards in Title 21 Code of Federal Regulations (Subchapter J, Radiological Health) Parts 1010 and 1040.

2.7 Basic of laser structure

Components involved in the laser cavity include, active medium, pumping mechanism, optical resonator, and delivery system. Active medium is one of the essential components of the laser and made up from a material which can be optically stimulated and produce laser light. There are few examples of the active medium such asgas container (CO_2 gas), a solid crystal such as yttrium, aluminium and garnet (YAG) crystal in neodymium (Nd) YAG laser, a liquid that is found in a few medical laser devices and a semiconductor found in diode lasers. It is usually placed inside the cavity of the laser, with two mirrors of optically parallel and highly reflecting with one of them is partially transmitting light to another. Besides, the active medium also must be able to amplify the light wave by stimulated emission.

The second component is the pumping mechanism. This mechanism is the primary source of energy. The pumping mechanism, such as flashlamp strobe device or electrical circuit functions to pump energy into the active medium. Energy supplied from this mechanism leads to the excited active medium and this leads to population inversion. The excited atoms or molecules spontaneously giving off energy in the form of a photon that allow light to travel in all directions in a laser cavity. Thus, the term ‘spontaneous emission’ is created from this phenomenon (Dent, 2008). Reza et al. (2011) also stated that the energy produced from pumping mechanism will be absorbed by the active medium, which then generates the laser light. Next is the optical resonator which functions to oscillate the light within the optical resonator and amplify the energy power. The position of two mirrors facing each other at each end will help in stabilising the bounced laser light produced by the active medium (Figure 2.5).The function of optical resonator with active medium is called optical oscillator. The delivery systems basically depend on the range of emitted wavelength. Examples of delivery systems include optical fibre, waveguide or articulated arm (incorporating mirrors).

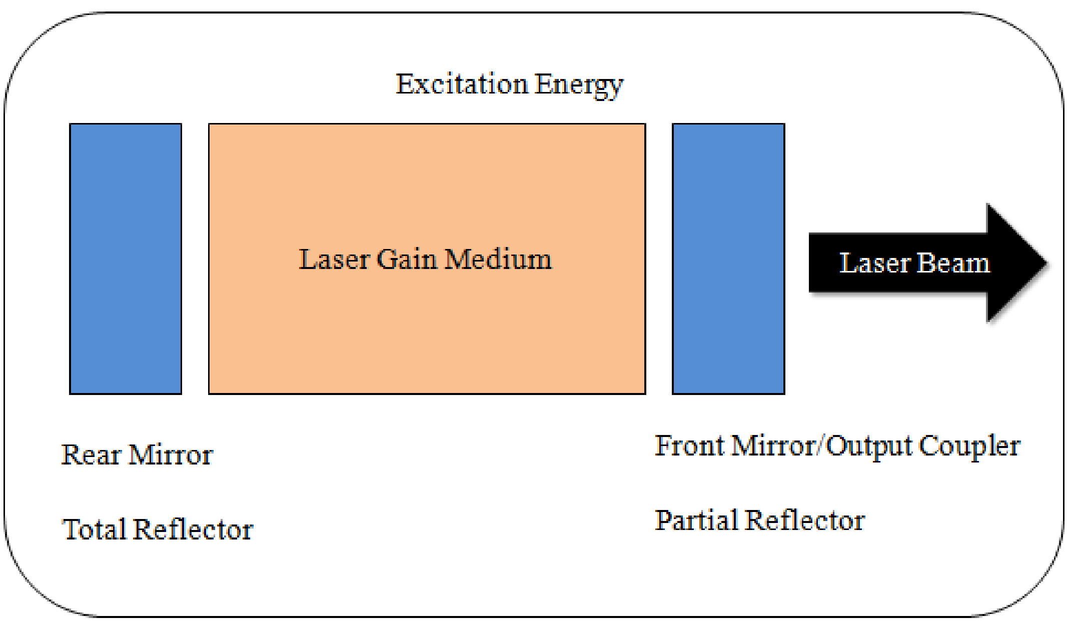

Figure 2.5 Basic laser structure (Adapted from Reza et al., 2011)

Fluence, wavelength and pulse duration are laser processing parameters which may influence the effectiveness of material removal mechanisms during laser ablation (Chrisey & Hubler, 1994). Energy can be defined as the ability to perform work and its common unit is in Joule (J). While, the measurement of optical energy delivered per area of spot size is known as fluence (F). Fluence is often expressed as Joules per square centimeter (J/cm^2). The calculation of laser fluence is based on the following equation.

$$\text{Fluence, F [J/cm}^2\text{]} = \frac{\text{Laser pulse energy [J]}}{\text{Effective focal spot area [cm}^2\text{]}} \quad (2.1)$$

Instead of fluence, the intensity of peak power is also used.

$$\text{Intensity, I [W/cm}^2\text{]} = \frac{\text{Laser peak power [W]}}{\text{Effective focal spot area [cm}^2\text{]}} \quad (2.2)$$

The laser peak power is calculated as below.

$$\text{Peak power, P [W]} = \frac{\text{Laser pulse energy [J]}}{\text{Pulse duration [s]}} \quad (2.3)$$

2.8 Application of Nd:YAG laser

Application of Nd:YAG laser in dental practice begins about 20 decades ago. Nd:YAG laser was the first true pulsed laser to be marketed exclusively for dental application in 1990 (Verma et al., 2012). Neodymium-doped with yttrium aluminium garnet (Nd:YAG) laser is equipped with a crystal that is commonly used as a lasing medium for a solid-state laser. The laser is optically pumped using a flash lamp or laser diodes and emits infrared light in the range of 1064 nm. The laser operates in both pulsed and continuous mode. Pulsed Nd:YAG laser also known as Q-switching mode. The 1064 nm laser is most highly absorbed by a pigment in the tissues, especially melanin, less absorbed in hemoglobin, and slightly absorbed in the water. The absorbance of Nd:YAG laser happens mostly in the bands between 730-760 nm and 790-820 nm. Because of its absorbance ability, this laser can work effectively for cutting and coagulating dental soft tissue with good homeostasis in clinical dental surgery (Maleki-pour et al., 2015).

In general, Nd:YAG laser is used for various applications in different areas of technology. For instance, in the field of oncology, this laser can be used to remove skin cancers (Moskalik et al., 2009). Besides, in the study of ophthalmology, the laser is applied to correct posterior capsular opacification, a condition that may occur after cataractsurgery (Steinert, 2013). This type of laser has the unique capacity to stimulate fibrin formation with longer pulse duration settings and also has excellent biostimulative properties (Pohlhaus, 2012).

In dental routine, neodymium laser is often used in multiple soft tissues procedures involving the oral cavity. The examples of Nd:YAG's soft tissue procedures are gingivectomy, periodontal sulcular debridement, treatment of aphthous ulcers, herpetic lesions, frenectomy, biopsy, as well as coagulation of graft donor sites (Myers & McDaniel, 1991). Minimum swelling, bloodless surgical field, proper coagulation, reduced surgical and postoperative pain are examples of the advantages of Nd:YAG laser for soft tissue applications. While, for hard tissue application, Nd:YAG laser seems to be useful for dentinal hypersensitivity, bleaching, caries removal and cavity preparation. This laser has a shorter wavelength, which is 1064 nm, same as diode laser (809 nm to 980 nm) and more likely to go deeper into soft tissues (Parker, 2007). Although Nd:YAG can penetrate in the deeper areas and near infrared wavelength, the clinicians must take precautions while carrying out the treatment due to the wavelength of Nd:YAG laser that is poorly absorbed by the water (Yova et al., 1995).

2.9 Laser effects on hard tissue

The application of laser in dentistry field commonly involves hard and soft tissue procedures. In dental hard tissue, the laser is used in many clinical routines such as cavity preparation (Prathima et al., 2015), dentinal hypersensitivity (Miglani et al., 2010), bleaching (Madhumathi, 2016), and caries prevention (Rezaei et al., 2011). Many studies has been conducted to investigate the changes of different morphological enamel and dentin structures under a scanning electron microscope after irradiated with the CO_2 laser (Takahashi et al., 1998) and Nd:YAG laser (Lin et al., 2001).

The first study of dental laser in hard tissue application was conducted by Goldman et al. (1964) on the effects of a pulsed ruby laser on human caries. The results showed completely destruction of enamel surfaces with the crater formations. Vahl (1968) demonstrated the effects of laser radiation on enamel by applying electron microscopy and x-ray diffraction which showed significant changes in enamel microstructure and crystallography due to irradiation. The study on the carbon dioxide (CO_2) laser on dental hard tissue produced detrimental effects on enamel, maximum loss of tooth structure, pits and fissures, and carbonisation (Gimbel, 2000). The application of CO_2 laser also might disrupt the odontoblastic layer (Wigdor, 1993). de Souza et al. (2009) revealed the existence of enamel granules and holes after Nd:YAG laser irradiation on enamel surface. Figure 2.6 shows the melting appearance of enamel surfaces after Nd:YAG laser irradiation and a presence of various sizes of enamel granules formed with small shallow cavities around them.

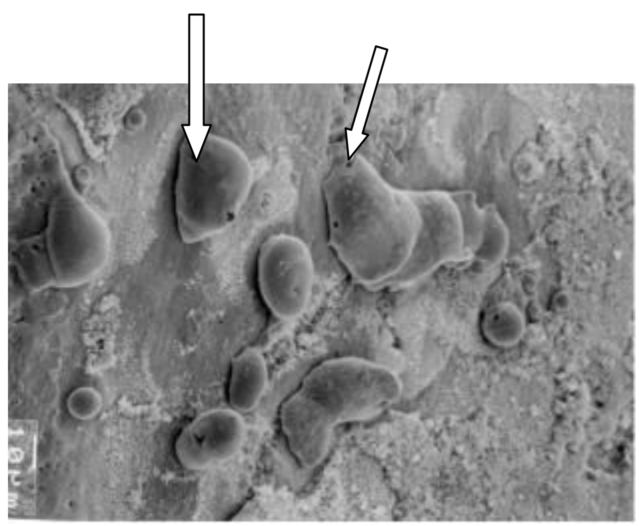

Figure 2.6 Surface of enamel irradiated with Nd:YAG laser. The presence of enamel granules (arrows) (Adapted from de Souza et al., 2009)

The effectiveness of laser to prevent demineralisation of teeth was proved to yield positive results since the 1960s. A few studies proved that the laser irradiation would increase enamel's resistance to demineralisation. Stern et al. (1966) concluded that the effect of a ruby laser on human enamel results in the increase of enamel resistance towards demineralisation in vitro. The study using Nd:YAG laser on enamel stated that the enamel became more resistant to subsequent dissolution (Yamamoto, 1980). The ability of laser to modify the crystalline structure and permeability of enamel lead to increase in enamel resistance towards demineralisation. One of the study evaluated the effect of both Nd:YAG and Er:YAG laser irradiation on deciduous enamel demineralisation (Hussain, 2012).

2.10 Laser effects on soft tissue

The benefits of the laser on soft tissues include promotes good precision, minimal swelling and scarring, less or no postsurgical pain and produces bloodless surgical and postsurgical course (Gold & Vilardi, 1994). Goharkhay et al. (1999) studied that diode laser has the ability to heal soft tissues (for example; gingiva) softly with no use of anesthetics. It also may reduce the bactericidal effect and improve the inflammation in the root canal (Moritz et al., 1998). There are specific applications of lasers in clinical dentistry routine includes gingivectomy, frenectomy, sulcus debridement, incisions and draining of abscesses and pulpotomy. Beside, lasers also been applied in the procedures of benign growths removal such as fibromas and papilomas (Abraham & Lankupalli, 2014). Figure 2.7 shows the soft tissue procedure using laser.

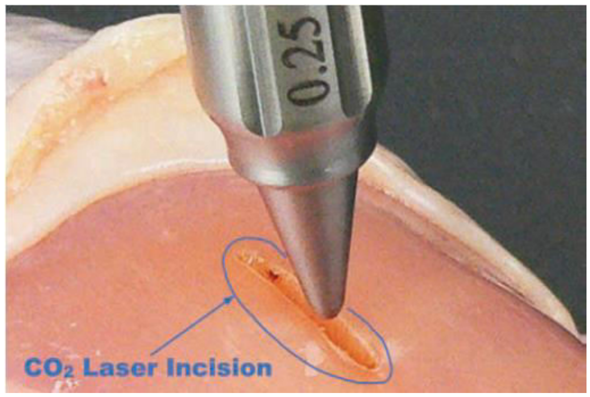

Figure 2.7 Laser irradiation on soft tissues (Peter, 2012)

Laser ablation can be defined as the laser heating process for removing a composite on a target material (Siniaeva et al., 2009). The absorption of electromagnetic radiation and redistribution of heat due to heat conduction are the two processes which determined the efficiency and level of heating. The selective and effective removal of dental tissues and inorganic dental materials (filling composites, ceramics and metal alloys) using a microsecond Nd:YAG laser (1064 nm) in the absence of dental tissue damage (Siniaeva et al., 2009). The ablation process by the Herculite and Prizmafil filling composites from the surface of enamel after bracket debonding was examined (Alexander et al., 2002). A graph of ablation rate (μm/pulse) versus laser fluence (J/cm^2) is shown in Figure 2.8 was determined.