Ablation of the Dentin and Enamel with a Femtosecond Laser for Faster and More Precise Cavity Preparation

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Abstract

Using a commercial femtosecond laser system with a high repetition rate, the current work aimed to quickly and precisely ablate enamel and dentin while avoiding collateral irreversible damage to the hard tissue and pulp.

The incident laser pulse fluence we used was slightly higher than the enamel and dentin ablation threshold. The hypothesis that a femtosecond laser operating at a repetition rate between 100 and 500 kHz could controllably ablate dental tissue while avoiding collateral irreversible damage to the hard tissue and pulp area was the foundation of the study.

Keywords: Femtosecond laser; Ablation by laser; Enamel and dentin; Dental depression arrangement

Introduction

Through the precise photocoagulation of the retina, lasers have been successfully utilized for eye surgery since the middle. Accordingly, ophthalmologists are the trailblazers in creating laser-based applications. Since then, lasers have been used in a wide range of scientific and industrial settings, and they continue to discover novel applications that will help the technology become more widely adopted.

Caries in the teeth causes pain and discomfort in 60–90 percent of school-aged children and nearly 100 percent of adults worldwide, according to the World Health Organization [1]. The dentin, which is the area between the enamel and the inner portion of the tooth that contains the nerve endings (pulp), is where the majority of tooth decay occurs. Dental decay and preparing a cavity in the tooth for a filling that will replace the lost structure are the primary uses of mechanical drills. Because these drilling operations are not precise enough, a significant amount of healthy enamel and dentin can be lost while the dental decay is being removed; Additionally, it is an invasive procedure that is uncomfortable for the patient. The uneasiness related with mechanical penetrating can be a mental hindrance for patients to defeat in looking for legitimate dental consideration. The majority of dental procedures necessitate the use of local anesthetic because of the drills' vibrations. In addition to removing any remaining tooth debris, a continuous spray of water is used in conjunction with the drills to balance the temperature rise caused by the friction between the drill and the tooth. As a result, using a laser light instead of a drill has a number of advantages. Because there is no contact, vibration, or noise, this technology is being accepted by patients more. What's more, there is pretty much nothing if no aggravation and inconvenience. In addition, the dentist may use a minimal dentistry approach in which only diseased tissue is removed while healthy tooth tissue is left intact.

Lasers are more secure contrasted with pivoting instruments because of an extremely okay of unintentional harm to the mash and delicate tissues. When compared to conventional instrumentation, calculator removal can be performed with some selectivity. In any case, those lasers utilized in dentistry so far have more undesirable than wanted impacts on the dental tissue [2]. Treatment with conventional pulsed laser sources, with pulse lengths ranging from ns to s, typically results in inadequate surface preparation and a relatively high thermal load. Cracking, melting, charring, fissuring, or crazing of tooth surfaces demonstrate this, which results in ineffective and uncontrolled removal of hard tissue. High powers are required because tooth structures do not absorb laser radiation well, resulting in excessive heat diffusion from the interaction area and the risk of intrapulpal damage. Long-pulsed lasers with a wide range of wavelengths have been used in previous studies to ablate human hard tissue. These lasers can generate a significant amount of heat in human teeth, especially if the pulse duration is too long.

Due to their precise and highly effective ablation capabilities and minimal thermal and shock wave collateral damages, high average power, high repetition rate, subpicosecond lasers have recently attracted development of surgical applications in dentistry. Shock wave, vibration, and temperature rise in bulk dental tissue surrounding the treated site are eliminated, eliminating the painful effects of the laser [3]. This is because of an increase in the laser peak power and a decrease in the duration of the laser pulses to the subpicosecond time range. As a result, the ablation mechanism is electrostatic, and the laser light is absorbed in a small amount of material, causing rapid ejection of electrons and then ions, thereby reducing heat transfer to the surrounding tissue. Compared to conventional long-pulse lasers, which use a thermally induced ablation mechanism, electrostatic ablation mechanisms produce distinct changes in tooth morphology, significantly less collateral damage to the tissue, and a decrease in the energy fluence required for significant material removal. Ablation is less effective and surface melting is observed at laser pulse lengths longer than 1 ps. On the other hand, ablation efficiency can be maximized at pulse durations between 130 fs and 1 ps while surface melting is less evident. The mid-ear bone ablation, the implantation of prosthetic joints, and dental ablation—such as the removal of hard tissue and caries for cavity preparation are the primary uses of subpicosecond lasers for hard tissue ablation.

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In the search for optimal parameters for dental applications, a number of studies using subpicosecond pulsed laser systems have been published. These studies investigated a variety of process variables: elective lasing mediums, frequencies, beat terms, redundancy rates, cooling supply, and so on [4]. There was general agreement regarding the advantages of subpicosecond pulsed laser systems, such as their capacity to precisely shape tooth cavities and ablate a variety of materials (dentin, enamel, composite fillings, and metals) with little or no collateral damage (cracks, melting, discoloration, etc.). Except for a slight discoloration of the enamel, no thermal damage was caused to the dentin or enamel by a fiber laser operating at 100 kHz in the femtosecond (fs) regime. In addition, the authors found that the fs laser interaction with the dental tissue was the most precise when they compared it to ps systems operating at different wavelengths and higher repetition rates (2 MHz), either with or without cooling. Rode et al., on the other hand, ablated enamel successfully using a 60 ps Q-switched Nd at 1 kHz with no visible cracking or heat effects: YAG laser prompted the staining of the region encompassing the removed square.

Materials and Procedures

A diamond saw was used to section caries-free human molars taken from the Birmingham School of Dentistry Tooth Bank into 2 mm slices perpendicular to their long axis, resulting in well-defined flat areas of enamel and dentin [5]. The cuts were cleaned with a crushing paper with water system, and in this manner with a precious stone suspension (3 μm) to get reflect wrapping up. To get rid of any debris, distilled water was used for 15 minutes of ultrasound sonication. Epoxy resin was used to adhere the slices to microscope slides so that the irradiated upper surface remained parallel to the laser beam. The tooth slice and its holder were then positioned on an optical scan head-controlled to deliver a laser beam with a maximum linear velocity of 2000 mm/s [6]. The tooth cuts were kept in physiological arrangement when trial and error and the excess dampness before laser light was taken out utilizing compressed air.

By varying the pulse energy, pulse repetition rate, and scanning speed, the laser parameters necessary for efficient ablation of the enamel and dentin were identified. Effective process settings were deemed to have satisfactory ablation rates, minimal thermal load, and no signs of collateral damage. For the single-shot regime with relatively low laser fluence, the following parameters were determined: the removal limit was ~2.0 J/cm2 for finish and ~1.6 J/cm2 for dentin, separately, in concurrence with different examinations. Enamel had an ablation rate of 600 m/pulse, while dentin had an ablation rate of 680 m/pulse. Synchronous estimation of the intrapulpal temperature climb in the tooth was directed during removal to keep away from irreversible harm of the mash [7]. To measure the temperature on the pulp surface opposite the ablated one, a straightforward setup was constructed. The purpose of the setup was to reenact a situation in which deep dental tissue needs to be ablated and the surrounding pulp's temperature rises significantly. Teeth utilized for mash pit temperature estimations were sliced longitudinally down the middle with the mash eliminated. A thermocouple connected to a computerized thermometer was set in the mash chamber near the crown and got utilizing superglue. Epoxy resin was then used to seal the chamber. The laser shaft was centered around the crown of the as-arranged tooth half. The temperature was recorded for a few seconds prior to the start of the laser irradiation and continued until the laser was turned off. Every ten milliseconds, temperatures were measured.

Removed regions in dentin and finish were imaged with an optical magnifying lens. The energy dispersive X-ray spectrometer was used in conjunction with System from Oxford Instruments (INCA). For the SEM imaging, hard tissue craters with a depth of 200 m were prepared. Underlying portrayal was performed with a Fourier change infrared magnifying instrument.

Results and Discussions

Examining with the laser pillar over the dental material as opposed to hitting in just a single point lessens to least the laser illumination of the solid tissue. Assuming the laser influences onto the dental tissue just in one position, which is comparable to profound boring, an extreme intensity gathering happens [8]. Utilizing the output head and the mechanized, the removal of the 1 mm3 region in the finish and dentin zones took ~350 and ~300 s, individually, which is identical to evacuation paces of 2.85 mm3/s and 3.33 mm3/s. The two materials' distinct compositions result in distinct ablation rates, which account for this distinction. Carbonated hydroxyapatite (CO3-HA), a mineral, makes up the majority of the tooth. compound recipe. It likewise contains water and natural parts, for example, proteins and lipids. The enamel is much harder than the dentin because it is mostly made of highly crystalline CO3-HA and contains less water and organic material. Dentin, on the other hand, is more fragile because it contains more water and organics but only. Laser-tissue collaboration relies upon the impact of the laser frequency on the different tissue treated. The collaboration of laser light with sound, demineralized and carious tissues, in essential or super durable teeth will be different because of the different water and natural substance, and consequently unique crystallinity.

Carious tissues are demineralized and more extravagant in water in examination with solid and additionally non-crucial teeth [9]. In this way, more energy is required for polish and less energy for dentin or carious tissue, contingent upon laser assimilation of various water and natural substance in the tooth. At first, an OM was used to examine all ablated slices, and there were no cracks in the enamel or dentin zones. Figure provides an illustration of a typical mirror-polished tooth slice that has been prepared for laser processing. 2 in which smaller images of 1 mm2 of ablated enamel and dentin are also included. Both materials' processed zones were uniformly ablated, and there was no collateral damage around the craters. SEM images with a higher resolution were used to back up this observation. The enamel's surface was smooth in high magnification images before laser processing, and the distinctive tubules that are found all over the dentin. The ablated regions displayed precisely defined vertical cavity sides and edges typical of ultrashort pulse laser interaction with tissue. The inertia of the scanning mirrors at the turning points did not result in the formation of deep pockets at the crater edges, as occurs when scanning a meandering design.

Images in great detail of the region between the intact enamel and the ablated dentin. As a result of the laser's interaction with the dental tissue, no cracks, discoloration, melting, or carbonization were observed respectively. The ablated enamel and dentin underwent morphological transformations at 3 g and h [10]. As opposed to the smooth flawless materials The laser interaction created numerous interconnected pores and high porosity in the enamel and dentin. An 8-bit image that depicts the dentin or enamel as white pixels and the pores as black pixels was used to estimate the porosity in percentages using the threshold method in Image software for image analysis. Enamel and dentin had respective porosities of 56.3 and 55.7%, as determined by the threshold method. The increment of tooth surface harshness fundamentally influences the holding of dental fillings to the tooth cavity [11]. After the clinician has prepared the cavity using the fs laser instrument, dental tissue with a higher roughness may be advantageous due to its larger surface area

and improved adhesion strength of the filling. After the laser ablation, the intact dentin's tubules were not visible, indicating that ablated tissue most likely blocked them. Sealing the dentinal tubules makes the tissue more resistant to the development of new caries and helps to prevent and treat early-stage carious lesions.

Conclusion

In this study, a cutting-edge subpicosecond laser with a high repetition rate was used to quickly and precisely remove enamel and dentin hard tissue. Craters with well-defined, precise vertical cavity sides and edges were discovered through imaging. The laser's interaction with the dental tissue did not cause any cracks, melting, discoloration, or carbonization. The fs laser ablation resulted in the removal of contaminants and a beneficial increase in roughness. Primary portrayal showed the absence of stage changes of the HA mineral demonstrating that no overheating happened because of the laser removal.

Modern subpicosecond-pulsed lasers with a high repetition rate promise significant drilling capabilities. A laser instrument for use in supportive dentistry wipes out the vibration of the dental drill, which likewise kills the gamble of causing microfractures in the tooth. A high dynamics subpicosecond pulsed laser could be integrated into a cavity preparation instrument thanks to the high processing efficiency of the laser used in this work.

Acknowledgement

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Conflict of Interest

None

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