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Histologic Evaluation of Bone Using the Quantum Square Pulse Er: YAG Laser: A Preliminary Study

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ABSTRACT

A recent advancement in the Er: YAG laser is the introduction of Quantum Square Pulse technology (QSP). The laser in QSP mode has demonstrated several advantages in animal studies and human cavity preparations in carious teeth. Advantages of the Er: YAG laser in QSP mode include a reduction in laser beam scattering and absorption of the debris cloud. Most important, minimal thermal damage has been observed in cavity preparations. However, use of this new laser technology has not been reported in osseous surgery procedures such as the harvesting of monocortical blocks of bone to reconstruct the maxilla or mandible in the specialties of oral and maxillofacial surgery and implant dentistry. The purpose of this study was to histologically analyze and compare thermal changes on the bone surface of monocortical blocks of bone harvested from the posterior mandible of two patients using the Quantum Square Pulsed Er: YAG laser (Light Walker AT, Fotona, San Clemente, CA) in non-contact mode and a conventional surgical bur in a high-speed drill in preparation for dental implant surgery. The histological results demonstrated no thermal damage to bone ablated at the specified laser parameters during the osteotomy procedures. Use of the QSP Er: YAG laser has demonstrated advantages over the conventional high-speed surgical drill and should be considered as a surgical instrument of choice in the harvesting of monocortical blocks of bone in preparation for placement of dental implants.

INTRODUCTION

Harvesting of autogenous monocortical blocks of bone to reconstruct the atrophic maxilla or mandible are routine surgical procedures performed in oral and maxillofacial surgery and implant dentistry. Conventional mechanical methods to procure blocks of bone from the ascending ramus and buccal cortical plate of the mandible can be accomplished with a surgical bur in a high-speed hand piece, oscillating saw, piezosurgery and manual instruments such as chisels and osteotomes [1-3]. However, there are disadvantages with these methods, such as bacterial contamination, deposition of foreign metal shavings into the surgical area, increased thermal temperature that can cause osteonecrosis of the bone and risk of damage to important anatomic structures [2-6]. For the patient who completes the surgery without general anesthesia, the vibration and sound from these instruments may be difficult to tolerate [7,8]. An alternative surgical technology that avoids all of the disadvantages is a laser that can ablate bone smooth and cleanly, and most important, avoid thermal damage to bone during the surgical procedure.

Since Maiman [9] developed the ruby laser in 1960, high energy lasers have increasingly been used in oral and maxillofacial surgery and dentistry. Most notably, the infrared erbium-doped yttrium aluminum garnet (Er:YAG) laser with an emission wavelength of 2940 nm for ablating hard tissues, such as enamel, cementum and bone [10-12]. Compared to mechanical methods mentioned above, use of the laser results in less bleeding, tissue trauma, edema, and thermal damage [10,12]. However, there is a paucity of reports regarding the everyday clinical use of lasers for osseous surgery in private practice. Reasons mentioned include the following: osteotomy times are longer compared to the conventional use of surgical burs and saws and the inability to control the depth of the osteotomy when used in non-contact mode [2,8,13].

Laser energy is developed by directing light of various spectra into a medium that amplifies photons and directs them as monochromatic light in the ultraviolet, visible or infrared regions of the electromagnetic wave spectrum [14,15]. The laser beam is directed at a target tissue with a fiber-optic delivery system attached to a hand piece and is then emitted continuously or pulsed. Photon amplification occurs through a media such as heterogeneous crystals (neodynium, yttrium, aluminum, garnet and erbium), or gases such as carbon dioxide, helium, neon or argon. Each medium generates photons characteristic of that specific wavelength. Various energy levels are utilized to cut, ablate and coagulate tissues. Such laser pulses are typically temporal in shape with a slow rise and decline time. The result is decreased laser ablation speed and scattering in the debris cloud that leads to uncontrolled and increased thermal damage in hard tissue [14,15].

The emission wavelength of the Er:YAG laser is highly absorbed by both water and hydroxyapatite that results in a thermomechanical ablation of hard tissue [14-18] However, it is not only the specific laser wavelength that can ablate hard tissue, but the short pulsed duration (high pulse intensity) and the accompanying water spray of the Er: YAG laser that ablation can be achieved with minimal thermal necrosis in the area of the surrounding bone [17-20]. Therefore, use of the Er:YAG laser in short pulsed duration and non-contact mode have demonstrated minimal thermal damage when used on bone, and has demonstrated accelerated osseous healing and osteoinduction [16-20]. This is due to the mechanism of laser energy that is rapidly deposited into the target tissue and avoids dispersion of thermal energy before tissue ablation. The purpose of this study was to histologically analyze and compare thermal changes on the bone surface of monocortical blocks of bone harvested from the posterior mandible using the Quantum Square Pulsed Er:YAG laser (Light Walker AT, Fotona, San Clemente, CA) in non-contact mode and a surgical bur in a high-speed drill.

LASER DEVICE

To increase ablation speed of lasers and decrease thermal damage to hard tissues, quantum square pulse (QSP) technology have been developed [21,22]. With QSP mode, square-shaped power pulses are produced which their duration can be controlled over a wide range of pulse durations. Each laser pulse is divided (quantized) into several shorter low energy pulses (pulse quanta) that follow (temporal spacing) one another at a fast rate **(Figure 1)**. Each pulse of short energy is higher compared to the pulse power of a single long pulse that can ablate hard tissue with greater speed and efficiency, but the short rapid pulses decrease laser beam scattering and absorption of the debris cloud with minimal thermal damage in the area of the surgical site. In contrast, with long pulse durations, ablation efficiency is reduced and thermal damage increased. Therefore, to avoid the effects of laser beam scattering, the pulse duration of all pulse quanta should be shorter before the debris cloud can develop. In this prospective study, the LightWalker Er:YAG (Fotona, San Clemente, CA) laser in QSP mode was used.

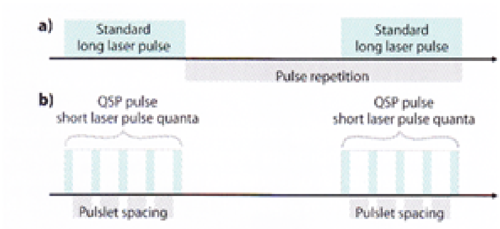

Figure 1. In QSP mode, a longer laser pulse is divided (quantized) into several short pulses (pulse quanta) that follow each other at a rapid rate.

This leads to the delivery of short pulses with the efficiency of long duration laser pulses. Such technology reduces laser beam scattering and absorption in the debris cloud during tissue ablation procedures.

MATERIALS AND METHODS

Twelve patients completed bone graft augmentation of the atrophic posterior mandible to increase the horizontal dimension in preparation for dental implant surgery. No preoperative antibiotics were prescribed. Informed consent was obtained from each patient participating in the study. Access to the ascending ramus to complete the osteotomy procedures was accomplished as described by Misch [23]. In each patient, a monocortical block of bone was harvested from the bilateral ascending ramus and buccal cortical plate of the mandible under local anesthesia. To protect the surgical staff during the laser surgical procedure, biosecurity standards were followed according to the laser manufacturer recommendations.

Laser Device

In the laser group, the LightWalker Er:YAG (Fotona, San Clemente, CA) laser in QSP mode was used. The handpiece (H14) to deliver the laser energy was attached to an articulated arm delivery system to complete the osteotomies using a sapphire chisel tip. The Er:YAG laser operated in non-contact mode with a constant water spray. Laser parameters were the following: wavelength fixed at 2.94 um; power: 7.5 W; pulse energy: 750 mJ; frequency: 10 Hz; QSP mode. To complete the osteotomy procedure, the sapphire tip was positioned perpendicular and 1 to 2 mm from the buccal cortical plate and was bathed in an air-water spray mist to avoid charring of osseous tissue.

On the contralateral side, each monocortical block of bone was harvested with a surgical bur 1.0 mm in diameter in a high-speed hand piece operating at 70,000 revolutions per minute (rpm) connected to an electrical motor under cool water irrigation.

RESULTS

A total of 24 ramus or buccal monocortical plate grafts were harvested from twelve patients to correct the atrophic posterior mandible in preparation for implant surgery. The study sample consisted of four monocortical blocks of bone from two patients for histologic analysis comparing thermal damage using the Er:YAG laser in QSP mode and a conventional surgical bur in a high-speed hand piece under cool water irrigation operating at 70,000 revolutions per minute.

Specimen Processing

All core bone biopsies were sent to the Hard Tissue Research Laboratory of the University of Minnesota School of Dentistry, Department of Oral and Maxillofacial Pathology for histologic analyses. To prevent bias in the study, the research scientist (HP) in the laboratory was blinded as the bone specimens were marked as specimen A and specimen B. Biopsy samples were fixed in 10% buffered formalin and submitted for histologic examination. All specimens were dehydrated with a graded series of ethanol for 9 days. After dehydration, each sample was infiltrated for 20 days with a light curing embedding resin (Technovit 7200 VLC, Kulzer, Wehrheim, Germany). The specimens were then embedded in Technovit 7200 VLC and polymerized by 450 nm light with the temperature of the specimens not exceeding 40°C. Each specimen was then prepared by the cutting and grinding method of Rohrer and Schubert [24]. Each specimen was cut to a thickness of 150 mm on an EXAKT cutting and grinding system (EXAKT Technolgies, Oklahoma City, OK). Each specimen slide was polished to a thickness of 55 microns with a series of polishing sandpaper discs from 800 to 2400 grit (EXAKT microgrinding system) followed by a final polish with 0.3-micron alumina polishing paste. Following final polishing, the specimen slides were stained using Stevenel's blue and van Gieson's picro fuchsin and subjected to histological evaluation by light microscopy. Specimens were evaluated using two slides to prevent sampling bias. Microphotographs were obtained, scanned, digitized and analyzed using a Zeiss Axiolab photomicroscope (Carl Zeiss, Jena, Germany) and Nikon Coolpix 4500 digital camera (Nikon Corp, Tokyo, Japan).

Histological Results

In the laser group, the bone specimens demonstrated sharp, clean margins **(Figure 2)**. There were no signs of thermal damage, as the laser osteotomy margins did not demonstrate charring, carbonization and microcracks. Osteocytes in their lacunae were observed directly next to the laser cut surface. In the surgical bur group, irregular borders were observed with bone debris. The margins of the cut edges demonstrated carbonization with an amorphous area indicating thermal damage **(Figure 3)**. Empty osteocyte lacunae are observed near the osteotomy margin. Empty osteocyte lacunae may represent total thermal damage of these cells.

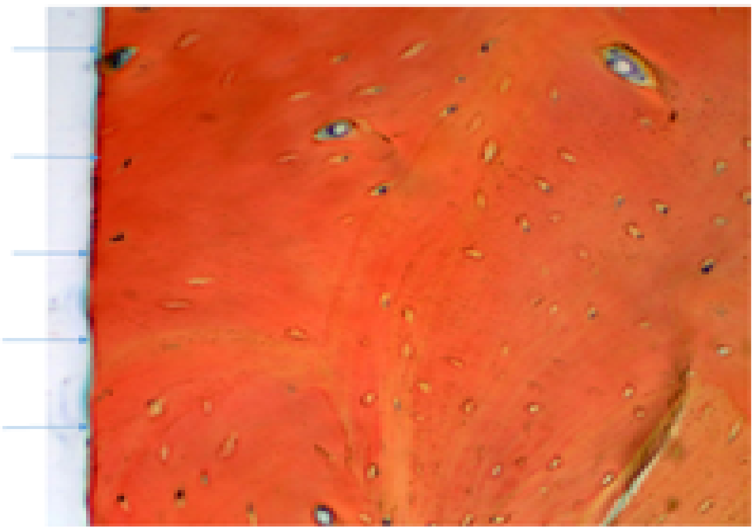

Figure 2. Osteotomy using the Er:YAG laser in QSP mode results in sharp clean margins without carbonization (blue arrows) (magnification x 100).

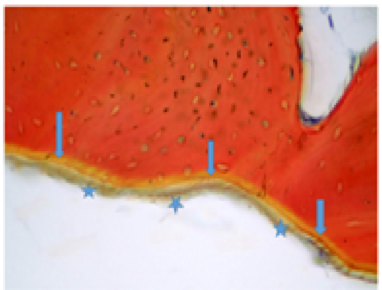

Figure 3. Osteotomy using surgical bur, brown colored amorphous layer (blue stars) due to thermal damage, layer of carbonization (blue arrows) on cortical side of osteotomy (magnification x 100).

DISCUSSION

To the best of the author's knowledge, a review of the world medical and dental literature on the clinical use of the QSP Er:YAG laser regarding osseous surgery in humans to harvest bone has not been reported. This prospective study analyzed the histological results using of the Er:YAG laser in QSP mode to the conventional surgical bur in harvesting monocortical blocks of bone in preparation for dental implant surgery. The use of autogenous bone for grafting in oral and maxillofacial reconstruction and dental implant treatment is the "gold standard" [25]. Autogenous bone is osteogenic, osteoconductive and osteoinductive [23,25]. The disadvantages of the conventional surgical drill and bur which is used most frequently for ostectomies and osteotomies despite their use with a water spray still results in osseous thermal damage, bone debris and necrosis of bone [2,10-13,16-18,20]. This is the driving force to develop and utilize new surgical technology.

Studies by Tokonabe et al. [26] Nair [27] and Pourzarandian et al. [28] demonstrated minimal thermal damage using natural teeth and bone, especially the pulp using the Er:YAG laser with a water spray. In a similar study to prepare human cavity preparations, the authors reported sharp well defined margins and minimal thermal damage with the use of the Er:YAG laser in QSP mode [21,29]. The results of this study using bone harvested from the posterior mandible have demonstrated excellent smooth and clean cutting efficiency without debris on the bone specimens with the Er:YAG laser in QSP mode **(Figure 2)**. Most important, the bone specimens demonstrated no thermal induced osteonecrosis and char-free ablation without microcracks. Such results are due to the QSP technology where using shorter laser pulses decreases the thermal load compared to long pulse laser durations that result in greater thermal damage and wound healing is increased.

In contrast, use of surgical burs to complete the osteotomy in harvesting bone may increase the focal temperature that can result in osteonecrosis. Allan et al. [30] observed increased temperatures and an area of necrosis after repeated use of a surgical drill in preparation for placement of self-tapping screws. Thermal damage of osteocytes may delay or prevent wound healing. In this prospective study, amorphous material was observed in the surgical bur group that was deposited in the area of the ostectomy using a surgical bur. In an ultrastructural study by Sasaki et al. [16] the amorphous material represented a reduction of the organic matrix of bone, microcracking and recrystallization of the surface apatite. Further, in a comparative study by Romeo et al. [31] surgical burs produced bone fragments and debris that has the potential to induce infections. Stubinger et al. [32] observed similar findings where the conventional surgical bur produced rough bone surface edges and debris compared to the use of an Er:YAG laser. No bone debris was observed with use of the Er:YAG laser decreasing the risk for postoperative infection.

CONCLUSION

In this prospective study, the Er:YAG laser in QSP mode has demonstrated advantages that were superior to use of a surgical bur for osseous surgery. Such advantages include clean cut margins, lack of a debris field and no thermal damage to bone. Use of the Er:YAG laser in QSP mode should be considered as an additional surgical modality compared to the conventional surgical high speed drill in the harvesting of monocortical blocks of bone in oral and maxillofacial surgery and implant dentistry. Further peer-reviewed clinical studies using a larger patient cohort are needed to establish the full potential of the digitally controlled QSP Er:YAG laser.

REFERENCES

1. Barone CM, et al. Analysis of bone formation after cranial osteotomies with a high speed drill. J Craniofac Surg. 1997;8:466-470.
2. Lee CYS. Procurement of autogenous bone from the mandibular ramus with simultaneous third-molar removal for bone grafting using the Er, Cr:YSGG laser: A preliminary report. J Oral Implantol. 2005;31:32-38.
3. Martins GL, et al. Bone healing after bur and Er:YAG laser ostectomies. J Oral Maxillofac Surg. 2011;69:1214-1220.
4. Kondo S, et al. Thermological study of drilling bone tissue with a high speed drill. Neurosurgery. 2000;46: 1162-1168.
5. Ishikawa I, et al. Effects of Er:YAG laser on periodontal therapy. J Int Acad Periodontol. 2003;5:23-28.

6. Eyrich GK. Laser–osteotomy induced changes in bone. Med Laser Appl. 2005;20:25-36.

7. Anic I, et al. Vibrations during erbium : yttrium-aluminum-garnet later irradiation. Lasers Med Sci. 2009;24: 697-701.

8. Hohlweg-Majert B, et al. Bone treatment laser-navigated surgery. Lasers Med Sci. 2010;25: 67-71.

9. Maiman TH. Stimulated optical radiation in ruby lasers. Nature. 1960;187:494-498.

10. Papadaki M, et al. Vertical ramus osteotomy with Er:YAG laser: A feasibility study. Int J Oral Maxillofac Surg. 2007;36:1193-1197.

11. Stubinger S, et al. Er:YAG laser osteotomy for removal of impacted teeth: Clinical comparison of two techniques. Lasers Surg Med. 2007;39:583-588.

12. Mello ED, et al. Comparative histological analysis of bone healing of standardized bone defects performed with the Er:YAG laser and steel burs. Lasers Med Sci. 2008;23:253-260.

13. Davidson SR and James DF. Drilling in bone:Modeling heat generation and temperature distribution. J Biomech Eng. 2003;125:305-314.

14. Kuttenberger JJ, et al. Bone healing of the sheep tibia shaft after carbon dioxide laser osteotomy: histological results. Lasers Med Sci. 2010;25:239-249.

15. Wallace RJ, et al. Experimental evaluation of laser cutting of bone. J Mater Proc Tech. 2004;149:557-560.

16. Sasaki KM, et al. Ultrastructural analysis of bone tissue irradiated by Er:YAG lasers. Lasers Surg Med. 2002;31:2322-2332.

17. Panduric GD, et al. Comparison of Er:YAG laser and surgical drill for osteotomy in oral surgery: An experimental study. J Oral Maxillofac Surg. 2012;70:2515-2521.

18. Panduric GD, et al. Morphological and ultrastructural comparative analysis of bone tissue after Er:YAG laser and surgical drill osteotomy. Photomed Laser Surg. 2014;32:401-408.

19. Frentzen M, et al. Osteotomy with 80-us CO2 laser pulses- histological results. Lasers Med Sci. 2003;18: 119-124.

20. Stubinger S, et al. Er:YAG laser osteotomy: Preliminary clinical and histological results of a new technique for contact-free bone surgery. Eur Surg Res. 2009;42:150-156.

21. Gutknecht N, et al. A novel quantum square pulse (QSP) erbium dental laser. J. Las Health Acad. 2011;1:15-20.

22. Lukac M, et al. Quantum square pulse Er:YAG lasers for fast and precise hard dental tissue preparation. J Laser Health Acad. 2012;1:14-21.

23. Misch CM. Ridge augmentation using mandibular ramus bone grafts for the placement of dental implants. Pract Periodontica Aesthet Dent. 1996;8:127-135.

24. Rohrer MD and Schubert CC. The cutting-grinding technique for histologicsal prepartion of undecalcified bone and bone-anchored implants: improvements in instrumentation and procedures. Oral Surg Oral Med Oral Pathol Endod. 1992;74-73-78.

25. Misch CM. The use of ramus grafts for ridge augmentation. Dent Implant Update. 1998;9:41-44.

26. Tokonabe H, et al. Morphological changes of human teeth with Er:YAG laser irradiation. J Clin Laser Med Surg. 1999;17:7-12.

27. Nair PN, et al. Pulpal response to Er:YAG laser drilling of dentine in healthy human third molars. Lasers Surg Med. 2003;32:203-209.

28. Pourzarandian A, et al. Histological and TEM examination of early stages of bone healing after Er:YAG laser irradiation. Photomed Laser Surg. 2004;22:342-350.

29. Mironov E. Case Report: Clinical experience with a quantum square pulse (QSP) Er:YAG laser. J Laser and Health Acad. 2012;1:80-85.

30. Allan W, et al. Effects of repeated drill use on temperature of bone during preparation for osteosynthesis self-tapping screws. Br J Oral Maxillofac Surg. 2005;43:314-319.

31. Romeo U, et al. Bone damage induced by different cutting instruments-An in vitro study. Braz Dent J. 2009;20:162-168.

32. Stubinger S, et al. Er:YAG laser osteotomy for intraoral bone grafting procedures: A case series with fiberoptic delivery system. J Periodontol. 2007;78:2389-2394.