Schneiderian Membrane Perforation Rate and Increase in Bone Temperature During Maxillary Sinus Floor Elevation by Means of Er:YAG Laser—An Animal Study in Pigs

Jacek Matys, DDS,* Jakub Hadzik, DDS,† and Marzena Dominiak, Prof‡

As a result of tooth extraction and natural process of alveolar bone remodelling, the walls of the alveolar ridge are subject to resorption. Bone deficiency in the vertical dimension often requires bone augmentation in the maxillary sinus before the planned implantation because of which placement of dental implants in the lateral part of the maxillla still presents a therapeutic challenge. Depending on the amount and quality of the bone, elevation of the maxillary sinus floor is performed as a one-stage procedure during implantation, with access through the alveolar ridge and preliminarily prepared implant bed (crestal approach) or with lateral access, that is, modified Caldwell-Luc method. Osteotomy during maxillary sinus floor elevation is performed with the use of various instruments such as traditional diamond drills, systems of specialist trephine burs used onto a low-speed handpiece with water cooling, and Piezosurgery or laser for hard tissues.

Purpose: To assess the time of preparation, bone temperature increase, and the Schneiderian membrane perforation rate during maxillary sinus floor elevation.

Materials and Methods: The research included 30 maxillary sinuses (n = 30) of a pig, divided into 2 groups (n = 15). The lateral bony windows were created using Er:YAG laser (200 mJ, 15 Hz, energy density: 25.48 J/cm²) and a diamond bur (control). The membrane was elevated using laser (50 mJ, 50 Hz) and hand instruments. The bone temperature was measured by K-type thermocouple.

Results: Significantly lower rates of the Schneiderian membrane perforation were found in the laser group (6.67%) compared with the bur (33%) (P < 0.05). The significantly higher increase in temperature (mean 7.6°C) was found in the experimental group as compared with the control group (mean 2°C) (P = 0.0000033). The average time necessary for the laser bony window osteotomy was 10 minutes and 37 seconds, whereas using the bur required middling 5 minutes and 50 seconds (P = 0.000283).

Conclusion: The application of Er:YAG laser may significantly reduce the risk of iatrogenic perforation of the Schneiderian membrane and does not cause an irreversible thermal damage in a pig model.

Key Words: maxillary sinus floor elevation, Er:YAG laser, Schneiderian membrane perforation

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surgery using lasers and is key factor for osseointegration process.21 Eriksson et al22 found that increasing the temperature of the bone tissue by 10°C for 60 seconds induces permanent changes in the bone structure; therefore, the tissue temperature gradient (ΔTa) below 10°C should be considered optimal and safe. Hence, the heat generated during the laser bony osteotomy is a major factor influencing surgery failure.21

The objective of the study was to assess the Schneiderian membrane perforation rate during the lateral window sinus elevation procedure performed with the use of the Er:YAG laser on an animal model. In addition, the assessment covered also the increase in temperature of the bone prepared with a beam of the Er:YAG laser and the time of a lateral window osteotomy. Furthermore, the time required to perforate the Schneiderian membrane during its direct irradiation using Er:YAG laser was assessed.

MATERIALS AND METHODS

Fifteen heads of 10-month-old male pigs (breed: Zlotnicka Biała), intended for consumption and which had been obtained from a butcher, were used in this study. Two different window osteotomy techniques were applied during maxillary sinus floor elevation.

Sample Preparation

In every head, preparation of the soft tissues gave access to the anterior and lateral walls of the right (n = 15)
and left (n = 15) maxillary sinus. The heads were washed under tap water and left for 4 hours in a container with water at a temperature of 22°C before the research was commenced. Ethical approval was not required for this animal ex vivo study.

**Surgical Procedure**

A bony window osteotomy (size 1 × 1 cm) was performed by means of Er:YAG laser (LiteTouch; Syneron Dental, Yokneam, Israel) with the following fixed operation parameters—energy: 200 mJ, frequency: 15 Hz, energy density per pulse: 25.48 J/cm², water spray cooling: 11 mL/min, tip angle: 70°, size of the tip: 1.0 × 17 mm, distance: 10 mm or a ball-shaped diamond bur for a low-speed contra-angle handpiece (Intra C09-C3 27:1; Kavo, Biberach, Germany) operated with a physiodispenser (Intrasurg300; Kavo), speed of the contra-angle handpiece: 1000 rpm, and water spray cooling: 20 mL/min in the right and left maxillary sinus, respectively. The Schneiderian membrane was elevated in the first step using a sinus elevator; next, the sinus membrane elevation was performed thanks to a laser photoacoustic effect induced by a chisel tip placed in a maxillary sinus filled with a water solution and then the procedure was completed by hand instruments. The operation parameters maintained during the sinus membrane elevation were as follows: energy: 50 mJ, frequency: 50 Hz, water spray cooling: 15 mL/min (Fig. 1).

**Measurement Procedure**

The temperature was monitored with a Medicare Clinical Products Gold mercury thermometer (Medicare Products Inc., New Delhi, India). The temperature of the bone was measured by means of a calibrated digital Thermocouple Meter TM-902C thermometer (Zhangzhou Weihua Electronic Co., Fujian, China) with the temperature probe of the K Thermocouple Probe, TP-02 type (Zhangzhou Weihua Electronic Co.). The measurement error was 0.5%. The temperature was measured in a continuous manner by means of a probe attached in the central point of the prepared bone window. The highest difference of the bone temperature was recorded (Fig. 2).

The time of the bone preparation was measured with a sports stopwatch SP17 XL-009A (Fuzhou Swell Electronic Co., Ltd., Fujian, China).

Additionally, the time required to perforate the Schneiderian membrane

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<th>Table 1. The Increase in the Temperature of the Bone Prepared With a Laser and Bur</th>
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<td>Mean value of temperature (ΔTa ± SD), °C</td>
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*Significant difference between experimental and control group; P = 0.0000033.

ΔTa indicates temperature gradient; SD, standard deviation.
exposed to the laser beam was measured while using the same methodology and operating settings as for the maxillary antrostomy. Two different operation modes were examined—in the first one, the laser tip was held still, whereas in the second one, the operator moved the tip 5 mm up and down.

**Statistical Analysis**

The obtained outcomes were subjected to statistical analysis by means of Statistica 10 (StatSoft, Krakow, Poland) software. The Student t-test for independent samples and U Mann-Whitney test were applied with the significance level $P < 0.05$.

**RESULTS**

A significant difference was recorded as regards the Schneiderian membrane perforation rate, that is, 6.67% in the case of an Er:YAG laser versus 33% in the control group ($P = 0.05$) (Fig. 3).

The analysis of the temperature of the bone tissue prepared with an Er:YAG laser revealed a significant increase in temperature (mean 7.6°C) in the experimental group compared with the control group (mean 2°C) ($P = 0.0000033$) (Table 1). The increase in temperature measured on the bone over 10°C (10.5°C) was reported only in one case during the laser irradiation. However, the osteotomy

* - significant difference compared to control group; $P = 0.0233$

**Fig. 4.** The Schneiderian membrane perforation rate in two groups.

* - significant difference between the groups; $P = 0.000001$

**Fig. 5.** Time required for the Schneiderian membrane perforation according to different operation modes.

**Fig. 6.** A laser ablation field on the Schneiderian membrane surface.
duration in the experimental group was significantly longer than that in the control group ($P = 0.000283$) (Fig. 4). The average time necessary for the laser bony window osteotomy was 10 minutes and 37 seconds, whereas that using the bur required middling 5 minutes and 50 seconds. The time required to perforate the Schneiderian membrane during its direct irradiation using Er:YAG laser was significantly shorter in the case of the laser head held still than when the operator moved the tip up and down ($P < 0.000001$) (Fig. 5). The direct irradiation of the sinus membrane using Er:YAG laser with fixed parameters (energy density per pulse: 25.48 J/cm², distance: 10 mm), did not cause a sinus membrane rupture mean up to 11 seconds of the laser irradiation when the tip was in constant movement (Fig. 6).

**DISCUSSION**

A maxillary sinus floor elevation by means of a modified Caldwell-Luc method with the lateral access and the use of a drill and Piezosurgery has been widely reported in the literature.10,23,24 However, there are few studies on the use of lasers during that procedure.11,25

The incidence of sinus membrane perforations when using a rotary instrument for sinus wall osteotomy, as reported in the literature, varies from 0% to 56%,13,26–34 One noteworthy exception is the study conducted by Romanos.35 Romanos used a round burr to prepare the osteotomy of the maxillary bone and did not observe perforation of the sinus membrane in the 56 cases (0% of failure rate). In our study, we obtained 33% of sinus mucosal perforation rate. The result corresponds with the study of Kazancioglu et al,33 who reported a rate of 32% of sinus membrane perforation.

Scarano et al8 showed in their studies a higher level of sinus membrane perforation rate by means of the rotary bur, compared with Piezosurgery. The authors recommend that the ultrasonic piezoelectric device is effective in making the replaceable bony window. In turn, Atieh et al23 stated in their study that the risk of sinus membrane perforation did not show any significant difference between the 2 surgical techniques (risk ratio, 0.87). The present work confirmed that for the bur the rate of sinus membrane perforation incidence is approximately 5 times higher in comparison with the erbium laser.

Pikos36 and Misch37 in their studies showed that perforation of sinus mucosa is the most common complication during lateral sinus window osteotomy. Erbium lasers are very useful during bone ablation21,38; however, there are fewer evidence on decreasing sinus membrane perforation frequency by means of lasers during lateral sinus lift.

Sohn et al,11 in their study conducted on 12 human maxillary sinuses, define the mean time required to open a bone window using the Er,Cr:YSGG laser to be 3 minutes 24 seconds. The result reported by Sohn et al11 differs from the mean outcomes obtained in the present work, which amounted to over 10 minutes. The difference may be caused by dissimilarities in the anatomical structure of the maxillary sinus bone wall of a pig and a human. Sohn et al11 used the Er,Cr:YSGG laser in their research; however, osteotomy of the bone plate over 3 mm thick was performed with a Piezosurgery unit. Thus, the results reported by the above authors do not fully represent the characteristics of the laser used to open the maxillary sinus. The perforation rate obtained by Sohn et al11 was 33.3%, which is much higher than our result (6.67%). Sohn et al11 reported the energy density used during their procedure to be 6 J/cm². In our study, we applied higher energy density, that is, 25.48 J/cm². However, higher energy does not necessarily mean overheating or greater risk of perforating the Schneiderian membrane as the key factors affecting absorption of the laser energy by the tissues are the distance between the laser tip and the tissue, constant movement of the tip, and adequate cooling of the bone tissue with water spray.39

Gabric et al38 assessed increase in the temperature of the bone prepared with the Er:YAG laser (energy: 1000 mJ; frequency: 20 Hz) and bone bur without cooling. They found a lower temperature increase in the group prepared with laser. In our study, we used water spray, which provided better cooling in the case of the tissue cut with a bur than with a laser. Kang et al40 do not recommend using laser for bone preparation because of strong carbonization of the tissue. The use of water spray during the operation of Er:YAG laser ensures low temperature increase (mean <10°C) and prevents carbonization after bone preparation, which was confirmed in our research.

The conducted study indicated that in 14 out of 15 cases, the temperature gradient ($\Delta$Ta) of the bone prepared during the open maxillary sinus lift was below 10°C. In line with the conclusions reached by Ericsson et al,22 increase in the tissue temperature below 10°C does not cause any changes in the bone structure. Therefore, within the limitations of this ex vivo study, the obtained outcomes indicate that it is safe to use laser during a sinus bone window osteotomy.

There is the only one case in our study where the temperature gradient during the bone osteotomy reached 10.5°C. This result does not differ much from critical threshold of 10°C. Furthermore, the study of Trisi et al44 showed that low-density bone seems to be more frail to heat-induced damage than high-density bone. Hence, for the osteotomy of the cortical bone of the sinus wall, the temperature gradient slightly higher than the critical threshold should not cause an irreversible thermal damage. However, our present work was an ex vivo study with all typical limitations, for example, a different chemical composition and the biological properties of the “ex vivo” specimens as compared with “in vivo” tissue, mainly because of the absence of the blood circulation. Thus, our findings should be confirmed in the human “in vivo” model as well.

Stubinger et al25 conducted research on temperature increase when opening a bone window in maxillary sinuses of human heads preserved in formalin and concluded that there were no visible carbonization or thermal damage in the bone after irradiation with the Er:YAG laser (1000 mJ, 12 Hz). In the above research, the Schneiderian membrane perforation rate amounted to 100%; however, as the
Furthermore, de Oliveira et al.42 showed irradiation of the specimens by Er,Cr:YAG laser. The authors pointed out that minimal damage in bone when using Er:YAG laser showed the lowest degree of thermal injury on the surface morphology by scanning electron microscopy of the bone osteotomy showed the lowest degree of thermal damage in bone when using Er:YAG laser. The authors pointed out that irradiation of the specimens by Er, Cr:YSSG caused the bone carbonization. Furthermore, de Oliveira et al.42 showed a shorter clinical time required to perform osteotomy in the bur group. The visible thermal injury of the bone was not reported in our study.

The authors are of the opinion that during opening lateral access to the sinus, the laser power should not exceed 200 mJ and the frequency should be 15 Hz, a safe distance should be maintained between the laser and the bone, and the laser tip should be in constant movement to ensure proper speed, precision, and safe cutting. The study results show that direct exposition of the sinus membrane to the laser beam emitted from the tip kept in constant movement at a safe distance of 1 cm perforates the Schneiderian membrane after 11 seconds.

We found promising results in the present work during the sinus membrane elevation by Er:YAG laser. The Er:YAG laser induced a photoacoustic wave in a water fluid after surgery with low energy (50 mJ) but with high frequency (50 Hz). This phenomenon allows to elevate the sinus membrane much more easily as compared with single use of the membrane elevators.

The Laser Induced Sinus Membrane Elevation technique generates a pressure (bubbles) in fluids because of the photoacoustic effect. A similar fluid movement induced by ultrasound (Piezoelectric Devices) can be also triggered by the erbium lasers but is based on different phenomena (photoacoustic effect). However, better results using laser could be achieved by designing a curved tip similar to the Piezosurgery tip, which are used in lateral window osteotomy and in sinus membrane elevation procedures. Unfortunately, there are no special sapphire tips on the laser handpiece designed for maxillary sinus floor elevation in the lasers currently available in the market. Additional studies are needed to confirm the results of the study in human research.

CONCLUSIONS

Prevention of bone overheating during preparation is of key importance for proper postsurgical healing of the tissues. The application of lasers during bone preparation to open access to the maxillary sinus may significantly reduce the risk of iatrogenic perforation of the Schneiderian membrane. It should also be kept in mind that during the laser operation, the tip should be kept in constant movement and the distance from the end of the tip to the target tissue should be about 10 mm, which prevents sudden damage of the sinus membrane and improves the safety margin.

DISCLOSURE

The authors claim to have no financial interest, either directly or indirectly, in the products or information listed in the article.

REFERENCES


