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‡

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 significant 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. (Implant Dent 2016;26:1–7)*

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

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[1,2] because of which placement of dental implants in the lateral part of the maxilla still presents a therapeutic challenge.[3,4] 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.[5,6]Osteotomy during maxillary sinus floor elevation is performed with the use of various instruments such as traditional diamond drills,[7,8] systems of specialist trephine burs[9] used onto a low-speed handpiece with water cooling, and Piezosurgery[10] or laser for hard tissues.[11] The most frequent complication after the maxillary sinus floor elevation is perforation of the Schneiderian membrane.[12–15] Wallace et al[10] report the rate of iatrogenic perforation of the Schneiderian membrane to be 7% using the Piezoelectric technique. There is one study describing Schneiderian membrane perforation rate during the procedure conducted with a laser in human model.[11] Sohn et al[11] analyzed 12 maxillary sinus osteotomies and reported Schneiderian membrane perforation in 33% of the surgeries performed with an Er,Cr:YSGG laser. Thermodynamic effects in bone produced by bur were widely described in literature.[16–18] When using laser for hard tissues, it is important to prevent excessive increase in the bone temperature. The laser used in bone surgery operates in the infrared spectrum at a wavelength of 2.78 (Er,Cr:YSGG) and 2.94 (Er:YAG) μm and show good absorption in water; hence, these lasers afford good results in bone surgical procedures.[19,20] Increase in temperature is extremely important during bone

*Phd student of Wroclaw Medical University, Department of Dental Surgery, Wroclaw, Poland.
†Assistant of Dental Surgery Department, Medical University of Wroclaw, Poland.
‡Head of Dental Surgery Department, Medical University of Wroclaw, Poland.

Reprint requests and correspondence to: Jacek Matys, DDS, Private Dental Healthcare, 67-400 Wschowa, Lipowa 18, Poland, Phone: 48-791-511-789, Fax: 71-784-02-53, E-mail: jacek.matys@wp.pl

ISSN 1056-6163/16/02601-001
Implant Dentistry
Volume 26 • Number 1

DOI: 10.1097/ID.0000000000000520

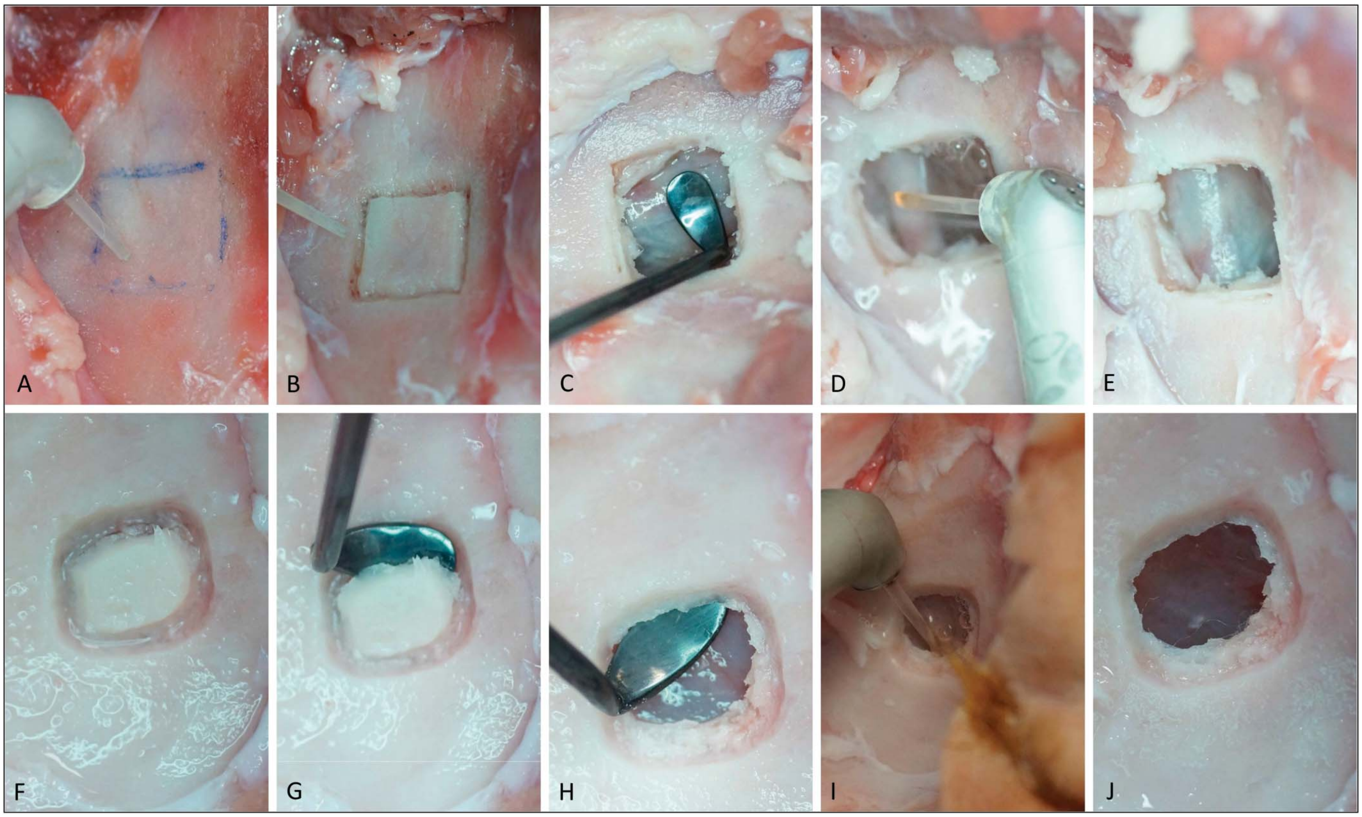

Fig. 1. Maxillary sinus floor elevation procedure using Er:YAG laser and a drill. **A**, Prepared cutting line. **B**, A bony window osteotomy (Er:YAG laser). **C** and **H**, A sinus membrane elevation by a hand instrument. **D** and **I**, Laser-induced sinus membrane elevation. **E** and **J**, The elevated sinus membrane. **F**, A bony window osteotomy (drill).

surgery using lasers and is key factor for osseointegration process.[21] Eriksson et al[22] 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.

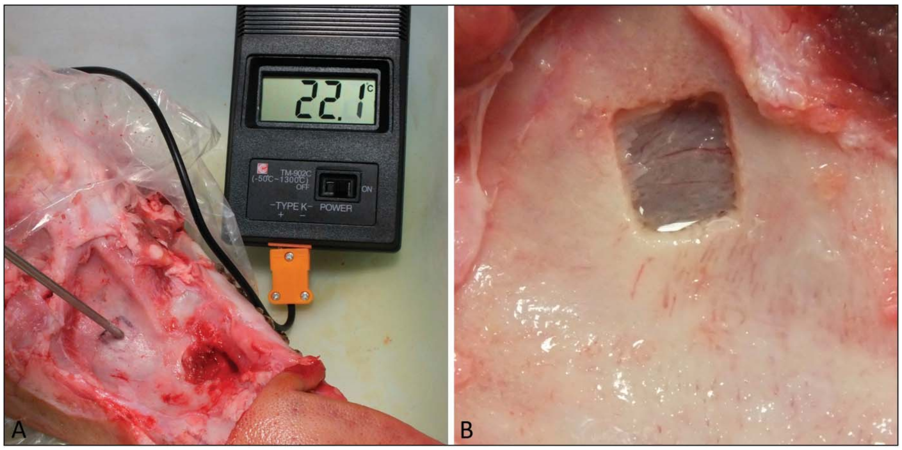

Fig. 2. Temperature measurement methodology. **A**, The thermocouple attached to the bone. **B**, The osteotomies accomplished by Er:YAG laser.

MATERIALS AND METHODS

Fifteen heads of 10-month-old male pigs (breed: Złotnicka 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/cm^2, 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

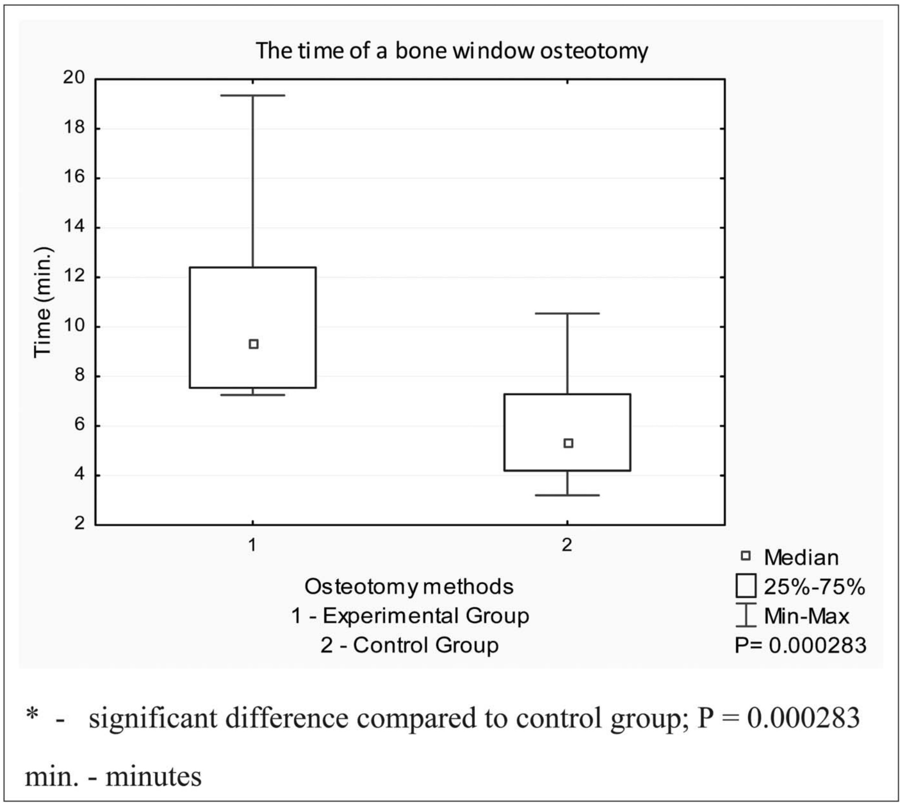

Fig. 3. The time necessary for the laser bony window osteotomy by means of Er:YAG laser and a bur.

Table 1. The Increase in the Temperature of the Bone Prepared With a Laser and Bur

Specimens (n = 15)	Control Group (ΔTa, °C)	Experimental Group (ΔTa, °C)
1	2.2	9.1
2	2.1	10.5
3	1.4	7.2
4	1.4	6
5	2.3	7.5
6	1.5	8.3
7	1.2	7
8	1.8	7.9
9	2.7	9.7
10	2.5	6.5
11	2.1	8
12	2.8	8.1
13	2.6	5.6
14	1.8	6.4
15	1.4	5.9
Mean value of temperature (ΔTa ± SD), °C	2 ± 0.53*	7.6 ± 1.43*

*Significant difference between experimental and control group; $P = 0.0000033$.
ΔTa indicates temperature gradient; SD, standard deviation.

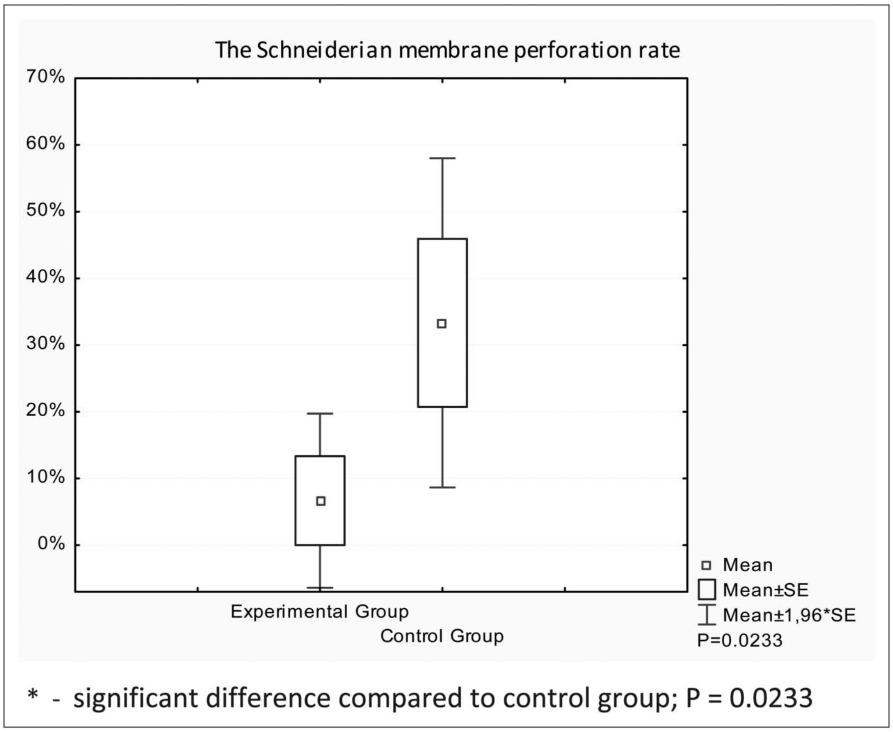

Fig. 4. The Schneiderian membrane perforation rate in two groups.

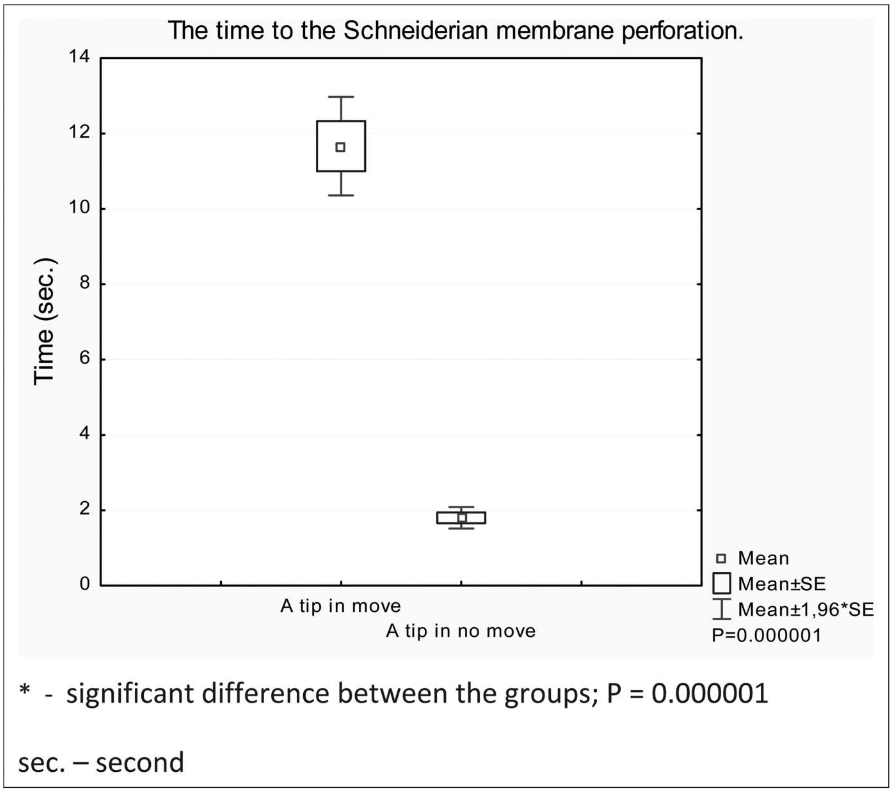

Fig. 5. Time required for the Schneiderian membrane perforation according to different operation modes.

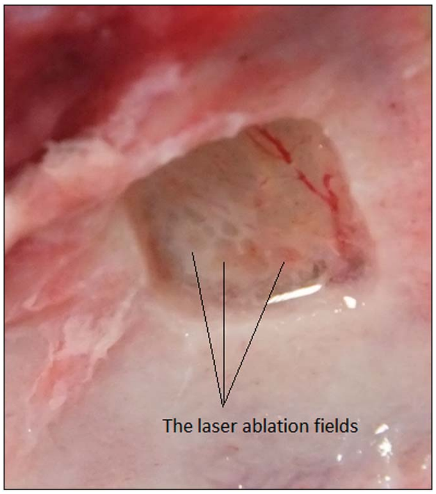

Fig. 6. A laser ablation field on the Schneiderian membrane surface.

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 <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 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/cm^2, 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 al[8] 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 al[23] 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 our 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.

Pikos[36] and Misch[37] 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 ablation[21,38]; 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 al[11] 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 al[11] 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 al[11] was 33.3%, which is much higher than our result (6.67%). Sohn et al[11] reported the energy density used during their procedure to be 6 J/cm^2. In our study, we applied higher energy density, that is, 25.48 J/cm^2. 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 al[38] 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 al[40] 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 (ΔTa) 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 al[41] showed that low-density bone seems to be more frail to heat-inducted 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 al[25] 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 authors themselves stated, the laser operation parameters and the procedure did not guarantee preserving continuity of the membrane during opening a bone window. The energy used in our research (200 mJ, frequency: 15 Hz, energy density per pulse: 25.48 J/cm^2) was much lower as compared with the study conducted by Stubinger et al.[25] However, the energy density per pulse of 25.48 J/cm^2 allows to cut a bone in precise and clean manner without any visible thermal damage and with a lower frequency of the Schneiderian membrane perforations incidents.

The recent an ex vivo study conducted by de Oliveira et al[42] revealed superiority of Er:YAG laser during bone surgery, as compared with the bur and Er,Cr:YSSG laser. The histological analysis and an evaluation of 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 Oliviera 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 curveted 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

1. Sharan A, Madjar D. Maxillary sinus pneumatization following extractions: A radiographic study. *Int J Oral Maxillofac Implants.* 2008;23:48–55.

2. Sornı M, Guarinos J, Garcıa O, et al. Implant rehabilitation of the atrophic upper jaw: A review of the literature since 1999. *Med Oral Patol Oral Cir Bucal.* 2005;10:45–56.

3. Tatum H. Maxillary and sinus implant reconstructions. *Dent Clin North Am.* 1986;30:207–229.

4. Corbella S, Taschieri S, Fabbro M. Long-term outcomes for the treatment of atrophic posterior maxilla: A systematic review of literature. *Clin Implant Dent Relat Res.* 2015;17:120–132.

5. Summers RB. Sinus floor elevation with osteotomes. *J Esthet Rest Dent.* 1998;10:164–171.

6. Woo I, Le BT. Maxillary sinus floor elevation: Review of anatomy and two techniques. *Implant Dent.* 2004;13:28–32.

7. Barone A, Santini S, Marconcini S, et al. Osteotomy and membrane elevation during the maxillary sinus augmentation procedure. *Clin Oral Implants Res.* 2008;19:511–515.

8. Scarano A, Mavriq L, Bertelli I, et al. Occurrence of maxillary sinus membrane perforation following nasal suction technique and ultrasonic approach versus conventional technique with rotary instruments. *J Craniofac Surg.* 2015;26:706–708.

9. Farre-Pages N, Auge-Castro ML, Alaejos-Algarra F, et al. A novel trephine design for sinus lift lateral approach. *Med Oral Patol Oral Cir Bucal.* 2011;16:79–82.

10. Wallace SS, Mazor Z, Froum SJ, et al. Schneiderian membrane perforation rate during sinus elevation using piezosurgery: Clinical results of 100 consecutive cases. *Int J Periodontics Restorative Dent.* 2007;27:413–419.

11. Sohn DS, Lee JS, An KM, et al. Erbium, chromium:yttrium-scandium-gallium-garnet laser-assisted sinus graft procedure. *Lasers Med Sci.* 2009;24:673–677.

12. Al-Dajani M. Incidence, risk factors, and complications of Schneiderian membrane perforation in sinus lift surgery: A meta-analysis. *Implant Dent.* 2016;25:409–415.

13. Schwarz L, Schiebel V, Hof M, et al. Risk factors of membrane perforation and postoperative complications in sinus floor elevation surgery: Review of 407 augmentation procedures. *J Oral Maxillofac Surg.* 2015;73:1275–1282.

14. Proussaefs P, Lozada J, Kim J, et al. Repair of the perforated sinus membrane with a resorbable collagen membrane: A human study. *Int J Oral Maxillofac Implants.* 2004;19:413–420.

15. Shlomi B, Horowitz I, Kahn A, et al. The effect of sinus membrane perforation and repair with Lambone on the outcome of maxillary sinus floor augmentation: A radiographic assessment. *Int J Oral Maxillofac Implants.* 2004;19:559–562.

16. Kerawala CJ, Martin IC, Allan W, et al. The effects of operator technique and bur design on temperature during osseous preparation for osteosynthesis self-tapping screws. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod.* 1999;88:145.

17. Kondo S, Okada Y, Iseki H, et al. Thermological study of drilling bone tissue with a high-speed drill. *Neurosurgery*. 2000;46:1162.

18. Allan W, Williams ED, Kerawala CJ. Effects of repeated drill use on temperature of bone during preparation for osteosynthesis self-tapping screws. *Br J Oral Maxillofac Surg.* 2005;43:314.

19. Wang X, Zhang C, Matsumoto K. In vivo study of the healing processes that occur in the jaws of rabbits following perforation by an Er, Cr: YSGG laser. *Lasers Med Sci.* 2005;20:21–27.

20. Pourzarandian A, Watanabe H, Aoki A, et al. Histological and TEM examination of early stages of bone healing after Er: YAG laser irradiation. *Photomed Laser Ther.* 2004;22:342–350.

21. Yoshino T, Aoki A, Oda S, et al. Long-term histologic analysis of bone tissue alteration and healing following Er: Yag laser irradiation compared to electrosurgery. *J Periodont.* 2009;80:82–92.

22. Eriksson AR, Albrektsson T. Temperature threshold levels for heat-induced bone tissue injury: A vital-microscopic study in the rabbit. *J Prosthet Dent.* 1983;50:101–107.

23. Atieh MA, Alsabeeha NH, Tawse-Smith A, et al. Piezoelectric surgery vs rotary instruments for lateral maxillary sinus floor elevation: A systematic review and meta-analysis of intra-and postoperative complications. *Int J Oral Maxillofac Implants.* 2015;30:1262–1271.

24. Rickert D, Vissink A, Slater JJ, et al. Comparison between conventional and piezoelectric surgical tools for maxillary sinus floor elevation. A randomized controlled clinical trial. *Clin Implant Dent Relat Res.* 2013;15:297–302.

25. Stubinger S, Nuss K, Sebesteny T, et al. Erbium-doped yttrium aluminium garnet laser-assisted access osteotomy for maxillary sinus elevation: A human and animal cadaver study. *Photomed Laser Surg.* 2010;28:39–44.

26. Hernández-Alfaro F, Torradeflot MM, Marti C. Prevalence and management of Schneiderian membrane perforations during sinus-lift procedures. *Clin Oral Implants Res.* 2008;19:91–98.

27. Testori T, Wallace SS, del Fabbro M, et al. Repair of large sinus membrane perforations using stabilized collagen barrier membranes: Surgical techniques with histologic and radiographic evidence of success. *Int J Periodontics Restorative Dent.* 2008;28:9–17.

28. Zijderveld SA, van der Bergh JP, Schulten EA, et al. Anatomical and surgical findings and complications in 100 consecutive maxillary sinus floor elevation procedures. *J Oral Maxillofac Surg.* 2008;66:1426–1438.

29. Papa F, Cortese A, Maltarello MC, et al. Outcome of 50 consecutive sinus lift operations. *Br J Oral Maxillofac Surg.* 2005;43:309–313.

30. Barone A, Santini S, Sbordone L, et al. A clinical study of the outcomes and complications associated with maxillary sinus augmentation. *Int J Oral Maxillofac Implants.* 2006;21:81–85.

31. Ardekian L, Oved-Peleg E, Mactei EE, et al. The clinical significance of sinus membrane perforation during augmentation of the maxillary sinus. *J Oral Maxillofac Surg.* 2006;64:277–282.

32. Geminiani A, Weitz DS, Ercoli C, et al. Comparative study of the incidence of Schneiderian membrane perforations during maxillary sinus augmentation with a sonic oscillating handpiece versus a conventional turbine handpiece. *Clin Implant Dent Relat Res.* 2015;17:327–334.

33. Kazancioglu HO, Tek M, Ezirganli S, et al. Comparison of a novel trephine drill with conventional rotary instruments for maxillary sinus floor elevation. *Int J Oral Maxillofac Implants.* 2013;28:1201–1206.

34. Seoane J, Lopez-Nino J, Garcia-Caballero L, et al. Membrane perforation in sinus floor elevation—Piezoelectric device versus conventional rotary instruments for osteotomy: An experimental study. *Clin Implant Dent Relat Res.* 2013;15:867–873.

35. Romanos GE. Window preparation for sinus lift procedures: A simplified technique. *Implant Dent.* 2008;17:377–381.

36. Pikos MA. Complications of maxillary sinus augmentation. In: *The Sinus Bone Graft*. Vol 9. 2nd ed. Hanover Park, IL: Quintessence Publishing Co, Inc; 2006:103–125.

37. Misch CE. The maxillary sinus lift and sinus graft surgery. In: Misch CE, ed. *Contemporary Implant Dentistry*. Chicago, IL: Mosby; 1999:469–495.

38. Gabric D, Bago I, Katanec D, 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.

39. Matys J, Dominiak M, Flieger F. Energy and power density: A key factor in lasers studies. *J Clin Diagn Res.* 2015;12:ZL01–2.

40. Kang HW, Oh J, Welch AJ. Investigations on laser hard tissue ablation under various environments. *Phys Med Biol.* 2008;53:3381–3390.

41. Trisi PI, Berardini M, Falco A, et al. Effect of temperature on the dental implant osseointegration development in low-density bone: An in vivo histological evaluation. *Implant Dent.* 2015;24:96–100.

42. de Oliveira GJ, Rodrigues CN, Perussi LR, et al. Effects on bone tissue after osteotomy with different high-energy lasers: An ex vivo study. *Photomed Laser Surg.* 2016;34:291–296.