Use of Er:YAG Laser to Improve Osseointegration of Titanium Alloy Implants—A Comparison of Bone Healing

Gavriel Kesler, DMD[1]/George Romanos, Dr Med Dent, DDS, PhD[2]/Rumelia Koren, MD[3]

Purpose: *The objective of this study was to compare the osseointegration of implants in rats in sites prepared with an Er:YAG laser with osseointegration in sites prepared using a conventional drill by assessing the percentage of bone-implant contact (BIC).* ***Materials and Methods:*** *Osteotomies were prepared with an Er:YAG laser in the tibiae of 18 rats (the test group) and drill-prepared with a 1.3-mm-wide surgical implant drill at 1,000 rpm with simultaneous saline irrigation in the tibiae of another 18 rats (the control group). Acid-etched titanium alloy implants (2 × 8 mm) were placed in the tibiae, engaging the opposite cortical plate. The Er:YAG laser was used with a regular handpiece and water irrigation (spot size, 2 mm; energy per pulse, 500 to 1,000 mJ; pulse duration, 400 ms; and energy density, 32 J/cm^2). Nine animals from each group were sacrificed after 3 weeks of unloaded healing; the remainder were sacrificed after 3 months. The tissues were fixed and prepared for histologic and histomorphometric evaluation.* ***Results:*** *Statistical analysis showed significant differences between the 2 groups at both 3 weeks and 3 months. After 3 weeks of unloaded healing, the mean BICs (±SD) were 59.48% (± 21.89%) for the laser group and 12.85% (± 11.13%) for the control group. Following 3 months of unloaded healing, the mean BICs (±SD) were 73.54% (± 11.53%) for the laser group and 32.6% (± 6.39%) for the control group.* ***Discussion:*** *Preparation of the implant sites with the Er:YAG laser did not damage the interface; the healing patterns presented were excellent.* ***Conclusions:*** *Based on the results of this study, it may be concluded that the Er:YAG laser may be used clinically for implant site preparation with good osseointegration results and bone healing and with a significantly higher percentage of BIC compared to those achieved with conventional methods.* INT J ORAL MAXILLOFAC IMPLANTS 2006;21:375–379

Key words: *bone-implant contact, Er:YAG laser, implant drills*

Recent technological advances have led to increased treatment options for dentoalveolar surgery. The traditional therapeutic techniques for bone removal have involved mechanical removal using various rotary instruments (eg, high- and low-speed, bone chisels, bone files).

It has been proposed that the use of a laser to cut and drill in bone could be clinically advantageous in comparison with the traditional method of using drills. Since there is no need to exert pressure on the bone, lasers may be superior to mechanical drilling.[1,2] A number of studies have demonstrated that the Er:YAG laser cuts bone precisely, with thermal damage of only 10 to 15 µm.[1–4] The low average power provides holes comparable to those obtained using mechanical drills. The laser removes a fixed amount of material per pulse, making precise control of cutting depth possible.[5–9] However, a previous study using a rabbit tibia model reported delayed healing of laser osteotomies compared with conventional saw osteotomies.[2]

To date few comparative clinical studies of osseointegration of titanium metal implants in Er:YAG laser-prepared bone have been performed.[5–7] The use of lasers for bone surgery requires careful histologic and histomorphometric evaluation of bone-to-implant contact (BIC) percentages and evaluation of healing at the drilling site.

[1]Private Practice, Petach Tikva, Israel.
[2]Clinical Professor, Department of Periodontology and Implant Dentistry, College of Dentistry, New York University, New York, New York.
[3]Lecturer, Department of Pathology, Sackler Faculty of Medicine, Tel Aviv University, Israel.

Correspondence to: Dr Med Dent George Romanos, Department of Periodontology and Implant Dentistry, College of Dentistry, New York University, 345 East 24th Street, New York, NY 10010. Fax: +212 995 4337. E-mail: gr42@nyu.edu

Fig 1 Er:YAG laser handpiece used for implant site preparation.

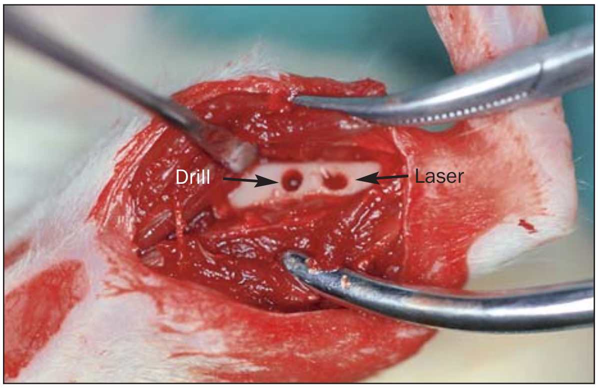

Fig 2 Implant sites prepared with the laser and a conventional drill in the tibia.

The purpose of this study was to assess bone response to titanium alloy implants placed in the tibiae of rats. Osseointegration in bony cavities created by both the Er:YAG laser and the mechanical drill method was assessed.

MATERIALS AND METHODS

Thirty-six male Sprague-Dawley rats weighing 350 to 400 g (4 months old) were divided into 2 groups of 18 animals. All rats were weighed to the nearest gram. Food and water were provided ad libitum throughout the experiment. The rats were anesthetized using volatile gas (enflurane), shaved, scrubbed, and draped to provide a surgical field. A 1.5-cm incision was made on the medial-proximal surface of the tibia above the tibial protuberance. Tissue was reflected to expose the flat portion of the tibia below the joint. In each animal, 1 implant site was prepared by a conventional drill and 1 site was prepared by laser. Only 1 of these sites, either the control site or the laser site, was studied for each rat.

Control Group

Eighteen rats served as a control group. Using a low-speed surgical handpiece with a no. 4 round bur and continuous saline irrigation, a pilot hole was drilled in the tibia 8 mm proximal to the tibial protuberance. A surgical implant drill 1.3 mm in diameter (1,000 rpm) was used to create an oblique-transverse osteotomy through the medullary canal and the opposite cortical shaft. Rather than drilling perpendicular to the bone, an oblique path of implant placement was used to optimize the implant surface area in the canal of each specimen. A no. 6 round bur was used to increase the size of the hole in the medial aspect of the tibia. The osteotomy was irrigated with saline solution.

Laser Group

Eighteen rats served as a laser group. The laser used was an Er:YAG (Opus 20; Lumenis, New York, NY) with a regular handpiece and water irrigation (Fig 1). The following parameters were used: spot size on tissue was 2 mm; energy per pulse was 500 to 1,000 mJ; pulse duration was 400 ms; repetition rate was 10 pulses per second (pps); and energy density was 16 to 32 J/cm^2. Ten to 15 pulses were typically used to drill through the tibia. The bone volume removed per pulse was 1.4 mm^3. The crater depth for the 2-mm spot size and the handpieces used was calculated to be 0.66 mm per pulse. The cavities created were further enlarged to accommodate the implants by slight translation of the beam around the circumference of the bony defect, which required additional 5 to 10 pulses (Fig 2). A special gauge was manufactured in different sizes and diameters to control the prepared cavity size. Although the shape of the osteotomy was not cylindric, with a 2-mm diameter throughout, in all cases the width of the laser cavity was 2 mm at its widest point to ensure that the laser osteotomies were comparable with one another. This less time-consuming technique was chosen because the ablation efficiency was noted to be drastically reduced and spot size increased due to continuous pooling of blood.

For the 2 groups, immediately after implant site preparation, acid-etched titanium alloy implants, 2 mm wide and 8 mm long (Alpha Bio, Petach Tikva, Israel), were placed by hand to engage the opposite cortical shaft in the tibiae of all rats for primary stability. Primary closure was achieved for each animal by approximating the muscle layer with sutures and closing the skin with surgical staples.

Nine rats from each group were sacrificed after 3 weeks of unloaded healing; the remaining rats were sacrificed after 3 months of unloaded healing. The implants with the surrounding tissues were then prepared for histologic examination.

Specimen Preparation for Histologic Evaluation

Tibiae and the implants with the surrounding bone were removed, cleaned of soft tissue, and fixed in 10% buffered formalin. For both groups implant specimens were dehydrated using a series of ascending alcohol-water solutions, ending with 100% alcohol. Specimens were then infiltrated with Remacryl acrylic resin, first with a 50% ethanol/resin solution and then with 100% resin. Photopolymerization of the resin was completed during 48 hours of exposure to blue light. After polymerization, the blocks were ground to remove excess resin and expose the implant-bone specimens. Specimen blocks were attached to plastic slides using a methacrylate-based adhesive. Histologic sections were cut perpendicular to the raised line on the head of each test implant. A Micromet high-speed rotating-blade microtome (Remet, Utica, NY) was used to obtain 200 to 250-μm-thick sections. Each section was reduced to a thickness of 40 μm using waterproof grinding papers of decreasing grit sizes. A polishing cream (grit size of 3 μm) was used for final polishing.

Histologic sections were stained using toluidine blue. Digitized images of each histologic section were acquired using a light microscope and a 10× objective connected to a high-resolution Hitachi KP-113 solid-state camera and frame-grabber computer hardware (Hitachi, Tokyo, Japan). All digitized images used for histomorphometric analysis contained the entire perimeter of each test implant. A histomorphometric analysis of the digitized images was performed using KsLite (Kontron Elektronik, Eching/ München, Germany) image analysis software. Histomorphometric values were scored as a percentage of BIC, beginning at the first thread crest below the head of each test implant. The percentage of BIC for each implant surface was calculated using half of the implant perimeter from the crest of the first thread below the head of the implant to the apex of the implant as the denominator and the actual BIC along the implant surface as the numerator. Data from each specimen were evaluated.

Statistical Evaluation

Comparison between the 2 groups (laser and control) regarding BIC was performed using the Mann-Whitney test. The statistical significance level was set to .05, and SPSS for Windows software version 11.0 (SPSS, Chicago, IL) was used for the analysis.

RESULTS

Healing in all surgical sites progressed normally without complication or exposure of either the control- or laser-group implants. At the time of re-entry surgery, all laser- and control-group implants were completely surrounded by bone, were stable, and had clinical and radiographic features consistent with complete osseointegration. The bone remained firmly affixed in closed contact with the implants during removal and subsequent histologic processing.

Histologic and Histomorphometric Findings

After 3 weeks of healing, the control-group implants were in close contact with the surrounding bone. New woven bone was found on the implant surfaces, giving the appearance of a carpetlike distribution (Fig 3a). More newly formed bone was observed in close contact with the titanium surface in the test group than in the control group (Fig 3b).

After 3 months of healing, new trabecular bone formation was observed in close contact with the titanium surface in the control group (Fig 4a) as well as the laser group (Fig 4b).

After 3 weeks of healing, histomorphometric analysis demonstrated BIC of 59.48% in the laser group versus 12.85% BIC for the control group (Table 2, Fig 5). After 3 months of healing, BIC of 73.54% was calculated for the laser group versus 32.65% BIC for the control group (Table 2, Fig 5). Mean BIC values and SDs for the laser and control groups after 3 weeks were compared with values after 3 months, and a statistically significant difference ($P < .001$) was found between the 2 time periods (Table 2). The results for the laser and control groups were also found to differ significantly ($P < .001$).

DISCUSSION

The study was designed to compare the BIC and the pattern of bone growth along titanium implant surfaces in osteotomies prepared by Er:YAG laser compared with osteotomies prepared using a conventional method. An evaluation of the histologic sections revealed that laser-prepared bone had a higher percentage of BIC at the implant interface than drill-prepared bone.

Based on the results of this study, it may be assumed that the Er:YAG laser can be used clinically for implant site preparation with very good results with respect to osseointegration and bone healing, with a statistically significantly higher percentage of early bone contact compared to the conventional methods.

Although the hole prepared by the drill was smaller (diameter of 1.3 mm) than that prepared by the laser (diameter of 2 mm), the BIC percentage was lower in the control group. BIC percentage may not have been increased because of bone condensing during implant placement, because of the hollowness of the rat tibia.

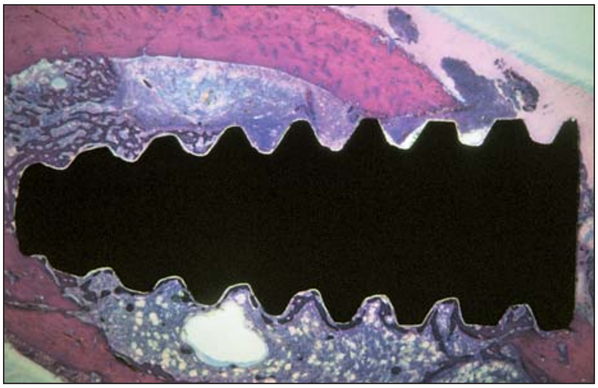

Fig 3a Histologic analysis of the implant and peri-implant tissues 3 weeks after implant placement in the control group. Newly formed woven bone was observed in close contact with the titanium surface (toluidine blue; original magnification ×25).

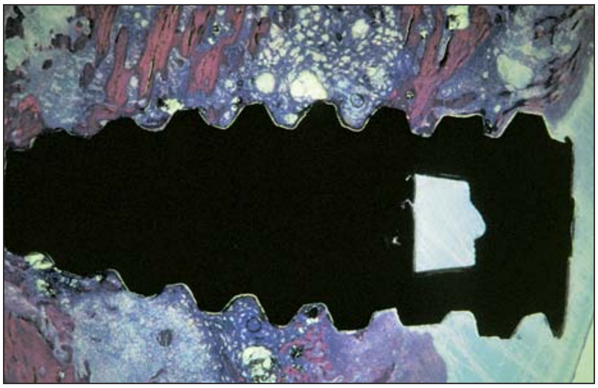

Fig 3b Histologic analysis of the implant and peri-implant tissues 3 weeks after implant placement in the laser group. Newly formed woven bone was present at the bone-implant interface (toluidine blue; original magnification ×25).

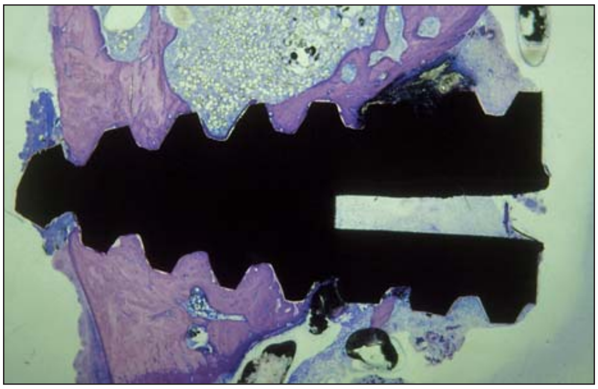

Fig 4a Histologic analysis of the laser group 3 months after implant placement showing new bone formation in close contact with the implant surface (toluidine blue; original magnification ×25).

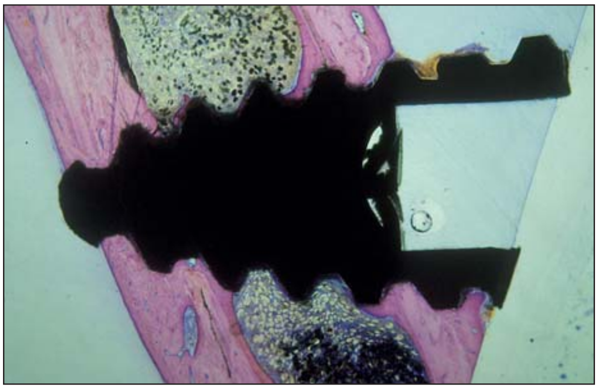

Fig 4b Histologic analysis of the control group 3 months after implant placement showing new bone formation at the bone-implant interface (toluidine blue; original magnification ×25).

Table 1 BIC (%) for the Laser and Control Groups (n = 36)

	n	Mean	SD	SEM
3 weeks				
Laser	9	59.48	21.89	7.29
Control	9	12.85	11.13	3.71
3 months				
Laser	9	73.54	11.53	3.84
Control	9	32.65	6.39	2.13

Table 2 Descriptive Statistics for the 36 Rats

Follow-up period	n	BIC (%) Minimum	Maximum	Mean	SD
3 weeks	18	0.41	92.61	36.16	29.31
3 months	18	22.05	88.33	53.09	22.89

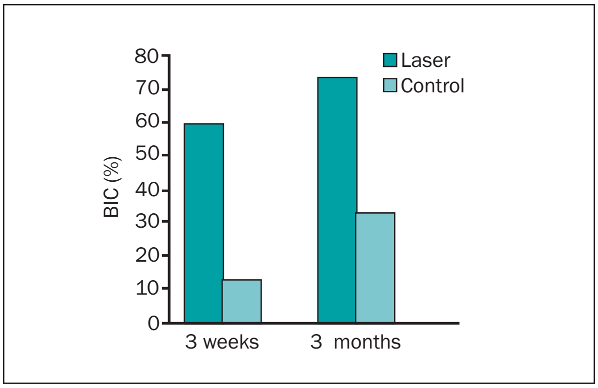

Fig 5 BIC for the laser and control groups at 3 weeks and 3 months after implant placement. BIC was significantly higher for the laser group at both time periods ($P < .001$).

Healing of the lasered bone resulted in adequate amounts of new bone around the titanium implants. In addition, collateral bone damage was less than in the bur-prepared bone. The bur may have caused bone necrosis, despite use of a low bur speed, perhaps because of the difficulty of applying sufficient coolant between the bone and the drill bit. By externally irrigating the bone with saline solution during the laser treatment, it was possible to reduce carbonization of the bone and enhance healing of the laser implant site. The Er:YAG laser irradiation conditions used in this study, particularly the use of coolant to prevent major thermal damage without affecting efficacy, were considered the most suitable conditions for clinical bone ablation.[10]

Sasaki and colleagues[11,12] demonstrated in their study that Er:YAG-lased surfaces revealed no severe thermal damage and only minimal changes, such as microstructural changes of the original apatites and reduction of the organic matrix, limited to an area approximately 30 μm wide. Moreover, there were no toxic products on the Er:YAG-lased surfaces.[12] The typical irregular pattern presented by the irradiated tissue, which consists of biologic apatites surrounded by an organic matrix, might lead to an uneventful healing after laser irradiation. Lewandrowski and associates[13] have also reported that the healing rate following Er:YAG laser irradiation may be equivalent to or even faster than that following bur drilling. In addition, the lack of smear layer and the typical irregular pattern presented by the irradiated tissue may potentially enhance the adhesion of blood elements at the start of the healing process.[12]

CONCLUSIONS

It was concluded that bone ablation with the Er:YAG laser can promote the growth of new bone around placed titanium implants and that osseointegration can occur in osteotomies created using the Er:YAG laser. O'Donnell and colleagues[14] have reported similar laser-induced stimulation of bone growth. The faster rate of bone formation may allow earlier function and earlier implant loading when required. The results of this histologic study indicate that laser-prepared implant sites develop a significantly higher percentage of BIC compared with conventional bone preparation. The statistically significant differences in mean BIC values between the control and laser groups support the growing body of evidence that other mechanisms are involved with Er:YAG laser irradiation. Hence, more experiments to clarify the effect of the Er:YAG laser on new bone formation and the healing process of surgical sites are necessary. The effects of laser wavelengths on bone growth around implants is a subject for further animal studies.

REFERENCES

1. Keller U, Hibst R, Mohr W. Experimental animal studies on laser osteotomy using the erbium:YAG laser system [in German]. Dtsch Z Mund Kiefer Gesichtschir 1991;15:197–199.
2. Hibst R. Mechanical effects of erbium: YAG laser bone ablation. Lasers Surg Med 1992;12:125–130.
3. Nelson JS, Orenstein A, Liaw LH, Berns MW. Mid-infrared erbium:YAG laser ablation of bone: The effect of laser osteotomy on bone healing. Lasers Surg Med 1989;9:362–374.
4. Walsh JT Jr, Deutsch TF. Er:YAG laser ablation of tissue: Measurement of ablation rates. Lasers Surg Med 1989;9:327–337.
5. Walsh JT Jr, Flotte TJ, Deutsch TF. Er:YAG laser ablation of tissue: Effect of pulse duration and tissue type on thermal damage. Lasers Surg Med 1989;9:314–326.
6. el-Montaser M, Devlin H, Dickinson MR, Sloan P, Lloyd RE. Osseointegration of titanium metal implants in erbium-YAG laser-prepared bone. Implant Dent 1999;8:79–85.
7. el Montaser MA, Devlin H, Sloan P, Dickinson MR. Pattern of healing of calvarial bone in the rat following application of the erbium-YAG laser. Lasers Surg Med 1997;21:255–261.
8. Kimura Y, Yu DG, Fujita A, Yamashita A, Murakami Y, Matsumoto K. Effects of erbium, chromium: YSGG laser irradiation on canine mandibular bone. J Periodontol 2001;72:1178–1182.
9. Fried NM, Fried D. Comparison of Er:YAG and 9.6-microm TE CO (2) lasers for ablation of skull tissue. Lasers Surg Med 2001;28:335–343.
10. Visuri SR, Walsh JT Jr, Wigdor HA. Erbium laser ablation of dental hard tissue: Effect of water cooling. Lasers Surg Med 1996;18:294–300.
11. Sasaki KM, Aoki A, Ichinose S, Ishikawa I. Ultrastructural analysis of bone tissue irradiated by Er:YAG laser. Lasers Surg Med 2002;31:322–332.
12. Sasaki KM, Aoki A, Ichinose S, Yoshino T, Yamada S, Ishikawa I. Scanning electron microscopy and Fourier transformed infrared spectroscopy analysis of bone removal using Er:YAG and CO_2 lasers. J Periodontol 2002;73:643–652.
13. Lewandrowski KU, Lorente C, Schomacker KT, Flotte TJ, Wilkes JW, Deutsch TF. Use of the Er:YAG laser for improved plating in maxillofacial surgery: Comparison of bone healing in laser and drill osteotomies. Lasers Surg Med 1996;19:40–45.
14. O'Donnell RJ, Deutsch TF, Flotte RJ, et al. Effect of Er:YAG laser holes on osteoinduction in demineralized rat calvarial allografts. J Orthop Res 1996;14:108–113.