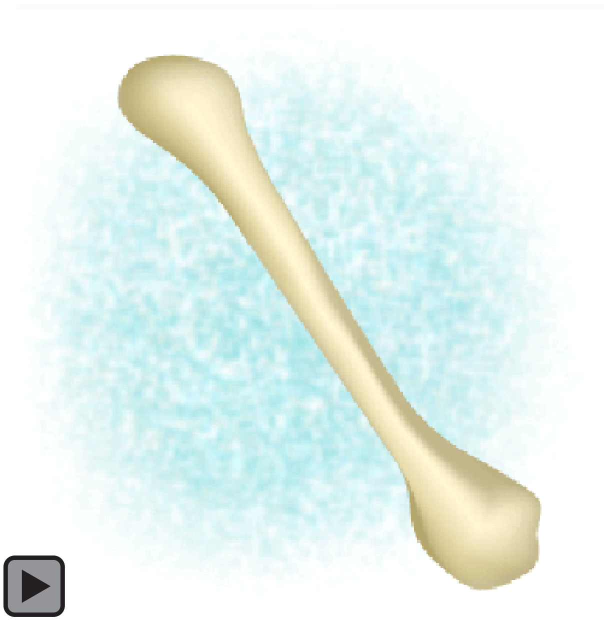
the Journal of CONTEMPORARY DENTAL PRACTICE
at www.thejcdp.com

Histologic Evaluation of the Effects of Er:YAG Laser on Bone Ablation

Utkan Kamil Akyol, PhD; Metin Güngörmüs, DDS, PhD; Cemal Gündogdu, DDS, PhD; Havva Erdem, PhD



Abstract

Aim: The aim of the present study was to compare the healing of bone defects created using an Er:YAG laser with those defects created using a surgical bone drill.

Methods and Materials: Fourteen Wistar rats were used for this study. Femurs were perforated with a surgical bone drill, coupled to a micromotor (bur group) to create a bone defect. Another defect was created using a 2940 nm wavelength Er:YAG laser on the same femur (Er:YAG Group). The Er:YAG laser was used with a energy density of 1.5 W in noncontact mode under a water coolant. Incisions were then sutured with polyglycolic acid sutures. Seven rats were sacrificed at day ten and the other seven at day 20 to compare the status of bone repair of each group at those post-surgical intervals. The femurs were fixed with 10% neutral buffered formalin and decalcified in 10% EDTA. The specimens were embedded in paraffin and sectioned at a 5 micron thickness and stained with hematoxylin and eosin (H&E) stain. The specimens were examined at a magnification of X100 and scored using a standardized histologic scoring system.

Results: Stages of bone healing including union, spongioza, cortex, and bone marrow development were evaluated and no significant difference between groups were found at days ten and 20 of healing. There was also no significant difference among the two groups in sum of histologic scores on day ten.

Conclusions: Bone can be ablated effectively and precisely using a Er:YAG laser without the vibration associated with steel surgical burs, but it is a slower process than when burs are used. There was no significant difference between the two groups in terms of bone repair at ten and 20 day intervals of healing.

Clinical Significance: Within the limits of this study a 2940 nm Er:YAG laser at 1.5 W can be used with confidence in cases requiring effective bone ablation.

Keywords: Bone ablation, surgical bone bur, Er:YAG laser, bone healing

Citation: Akyol UK, Güngörmüs M, Gündogdu C, Erdem H. Histologic Evaluation of the Effects of Er:YAG Laser on Bone Ablation. J Contemp Dent

Pract [Internet]. 2009 Sept; 10(5). Available from: http://www.thejcdp.com/journal/view/histologic-evaluation-of-the-effectsof-eryag-laser-on-bone-ablation.

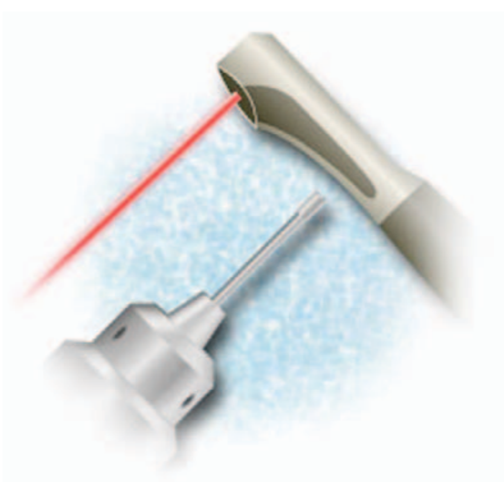
Introduction

With developing technology, new surgery procedures have been employed. Laser treatment is one of the new approaches widely used in hard and soft tissue surgery. Reported advantages of laser surgery include the following:[1]

- Sterilization of the surgical site while cutting tissue
- Simultaneous hemostasis of small vessels resulting in decreased bleeding and a dry surgical field
- Use of a “no-touch technique” for patient comfort
- Reduced postoperative pain
- Less edema
- Limited scarring

Studies in orthopedic[2,3,4] and oral and maxillofacial surgery[5] have suggested the pulsed Er:YAG laser is the most promising laser system for effective and precise removal of bone. The other advantages of Er:YAG laser in bone tissue surgery are as follows:[6]

- The absence of instrument vibration and pressure for patient comfort. (Lasers might be an alternative for replacing high and low speed surgical burs.)
- Removal of bone tissue in a location difficult to access by conventional methods.
- Bone ablation with precise, fast, and selective cutting.



The published literature has compared the use of the Er:YAG laser in osteotomy,[7] harvesting of intraoral autogenous block grafts,[8] implant surgery,[9] and removal of impacted teeth.[10] The present study compares bone healing in defects performed with the Er:YAG laser and with the use of the surgical bur.

Methods and Materials

Fourteen Wistar rats at the Ataturk University Faculty of Veterinary Animal Care Unit in Erzurum, Turkey were used for this study. The rats were housed two animals per cage in a room with a 12-hour light/dark cycle. All animal care and surgery were carried out in accordance with an approved protocol reviewed by Ataturk University Faculty of Veterinary Animal Care and Use Ethics Committee. Animals were given regular standard rat chow and water ad libitum throughout the experiment.

Each rat was anesthetized with ketamine (10 mg/kg) and xylazine hydrochloride (3 mg/kg) intraperitoneally. The left legs of the animals were shaved and cleaned with a 2% alcoholic iodine solution. A 2.0 cm longitudinal incision through the skin and subcutaneous tissue provided access to the femur through a small window without cutting muscle tissue to create two surgical defects in the bone. One defect was created with a surgical bur and the other with an Er:YAG laser. After surgical exposure, the distal epiphysis of the left femur was perforated to a diameter of 2.5 mm through the cortical and a 3 mm into medullary bone with a surgical bone drill coupled to a micromotor (1500 rpm) under constant flow of a sterile 0.9% saline solution (bur; control group). A second defect with similar dimensions was created using the Er:YAG laser on the same femur (Er:YAG group). The Doctor Smile laser (Lambda Laser Products, Vicenza, Italy) was used to induce the defect. This is a Class IV, Medical Class IIB with a laser source power of 15 W, at a network frequency of 50 Hz and an input power supply of 230±10% VAC. The Er:YAG laser was used at a wavelength of 2940 nm in noncontact mode under water coolant with a energy density of 1.5 W. The incisions were then closed with polyglycolic acid sutures. Seven rats were sacrificed at ten days post surgery and the other seven were sacrificed at 20 days in order to compare the progress of bone repair of each group.

Histopathologic Study

The femurs were fixed with 10% neutral buffered formalin and decalcified in 10% EDTA. The specimens were embedded in paraffin and sectioned to a thickness of 5 microns then stained with hematoxylin and eosin (H&E) and examined at a magnification of X100. The histologic analysis was performed using the histological scoring system developed by Heiple et al.[11] in which a maximum total score of 20 is possible when considering both proximal and distal bone formation in fracture areas.

Since there was only one-sided bone formation instead of two-sided (a bone cavity instead of a fracture) in the present study, only one value, either distal or proximal spongioza was extracted from the scoring system. Therefore, scores were obtained up to only a value of 16, then the statistical analyses of the data were done according to this scoring system (Table 1).

Scoring was carried out by two experts on histology, who were blind to the study groups. Data were analyzed with the Mann Whitney U test using SPSS 11.0 for Windows (SPSS, Inc., Chicago, USA) statistical analysis software.

Results

The ablation of bone with the Er:YAG laser was effective and precise, but required more time (10-12 seconds) than when using steel surgical burs (3-4 seconds). However, there was no vibration during bone removal with the laser compared to the steel burs or deposition of debris on bone. A decrease in bleeding was also observed with laser ablation.

Histological Results at Day Ten of Healing

In the histological study there was a fibrous union among the control group specimens. On the other

Table 1. Histologic scoring system.

Criteria	Description	Points
Union (Highest score = 4)	No sign of union	0
	Fibrous union	1
	Osteochondral union	2
	Bone union	3
	Complete reorganization	4
Spongiosa (Highest score = 4)	No sign of cellular activity	0
	Early bone formation	1
	Active new bone formation	2
	Reorganized spongiosa formation	3
	Complete reorganized spongiosa	4
Cortex (Highest score = 4)	Absence of cortex	0
	Early detection	1
	Initiation of formation	2
	Reorganization in majority	3
	Complete organization	4
Bone Marrow (Highest score = 4)	Not available	0
	Detection of fibrinous material	1
	Defect occupying more than half	2
	Fully occupying the red bone marrow	3
	Adult type fatty marrow	4
Sum of Histologic Scores		**16**

hand, there were areas where partial development of early and active new bone formation was evident in the spongiosa. Reorganized spongiosa formation was also observed along with bone marrow occupying more than half of the cavity in a few specimens. In most of the bone cavities there was fibrinous material in the control group (Figure 1).

A fibrous union and fibrinous material were found in all bone cavities of the Er:YAG group of specimens. In the histological preparation series there was partial evidence of the development of active new bone formation in the spongiosa (Figure 2).

In the present study union, spongioza, and bone marrow development were evaluated and no significant difference was found among the groups in terms of the sum of the histologic scores on day ten ($p > 0.05$) (Table 2). There was no cortex development observed in either group at day ten, therefore, it was not included in the statistical analysis.

Histological Results at Day 20 of Healing

At day 20, there was evidence of fibrous union in all bone cavities of both the bur and Er:YAG groups along with some areas of early and active new bone formation in the spongiosa. Reorganized spongiosa formation was observed in a few specimens. Fibrinous material was also present in most of the bone cavities in both groups. Bone marrow occupied more than half of the bone defect in a few specimens of the bur and Er:YAG laser groups (Figure 3-4). No cortex development was observed in either group at day 20.

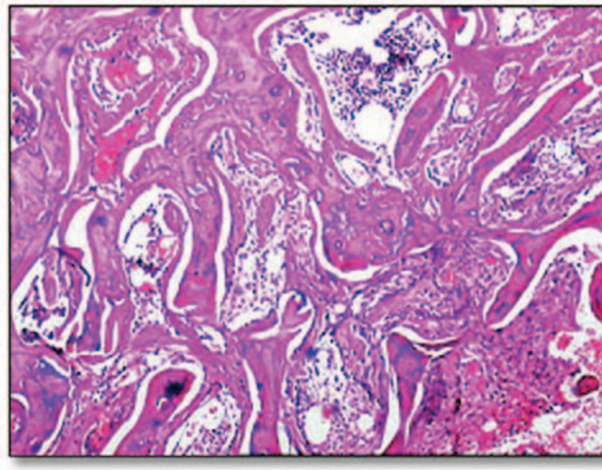


Figure 1. Photomicrograph of a tissue sample from an animal in the control group (surgical bur) at day ten. (H&E, original magnification X100).

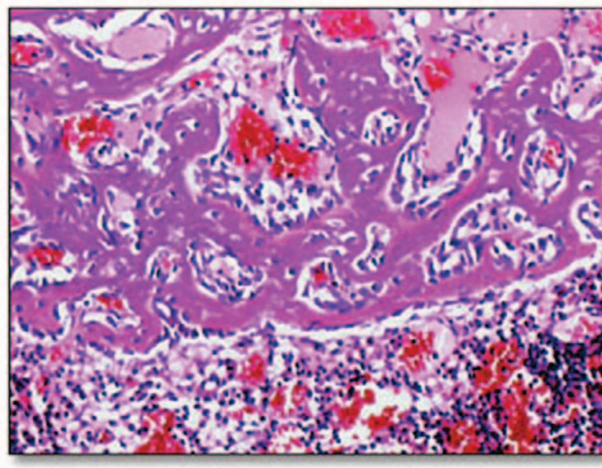


Figure 2. Photomicrograph of a tissue sample from an animal in the Er:YAG laser group at day ten. (H&E, original magnification X100).

Table 2. The effects of the Er:YAG Laser on bone repairment at day ten.

Criteria	Groups	Mean	SD	P
Union	Bur	1.00	0.00	>0.05
	Er:YAG Laser	1.00	0.00	
Spongiosa	Bur	1.85	0.89	>0.05
	Er:YAG Laser	1.42	0.78	
Bone Marrow	Bur	1.28	0.48	>0.05
	Er:YAG Laser	0.85	0.37	
Sum of Histologic Scores	Bur	4.14	1.34	>0.05
	Er:YAG Laser	3.28	1.11	

There was no significant difference between groups with regard to union, spongiosa, bone marrow, and the sum of histologic scores ($p > 0.05$) at day 20 of healing (Table 3). Since no cortex development was observed in either group at day 20, it was not included in the statistical analysis.

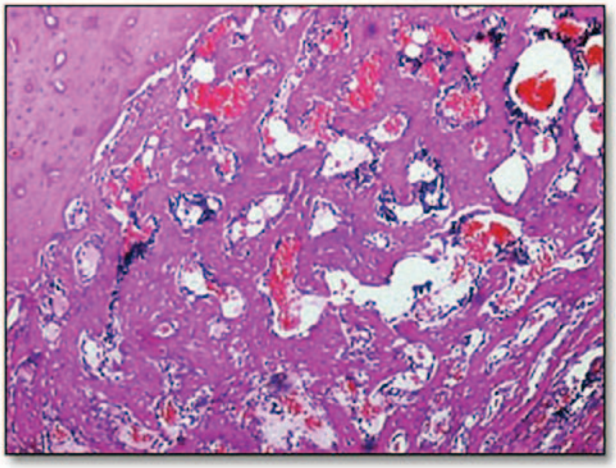


Figure 3. Photomicrograph of a tissue sample from an animal in group bur at day 20. (H&E, original magnification X100).

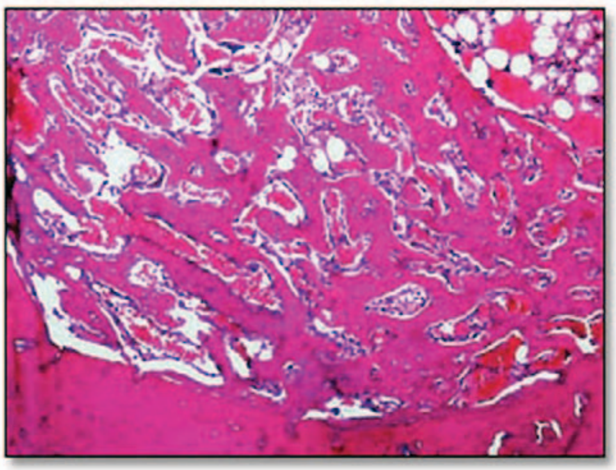


Figure 4. Photomicrograph of a tissue sample from an animal in group Er:YAG laser at day 20. (H&E, original magnification X100).

Discussion

The use of Er:YAG laser for ablating bone has become common in bone surgery. Investigators using the Er:YAG laser have reported ablating bone effectively with minimal thermal damage[12] and no adverse effects on bone healing.[6] Pourzarandian et al.[13] found more pronounced revascularization, faster bone healing, and a more favorable surface for cell attachment in calvarial bones in rats treated with a Er:YAG laser compared to either a mechanical bur or a CO_2 Laser. Nelson et al. reported the Er:YAG laser ablated bone effectively with minimal thermal damage to the adjacent tissues.[12]

Based on the results of the present study, the Er:YAG laser was found to ablate bone effectively and precisely, but requires more time than when steel surgical burs are used. The absence of vibration when the laser is used compared to steel burs provided comfort for the patient and surgeon during surgery. The results of Papadaki et al.[14] study were similar to those of the present study. One study[6] demonstrated the Er:YAG laser successfully promoted ablation of bone tissue by removing cortical bone, part of the medullar bone, and was an effective approach for an ostectomy procedure. Papadaki et al.[14] suggested pursuing the use of lasers for bone surgery because the

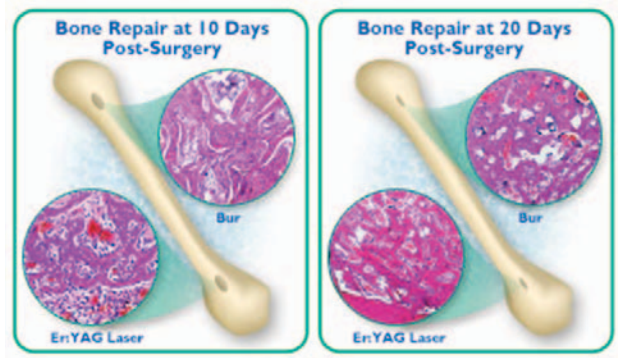
Table 3. The effects of Er:YAG Laser on bone repairment at day 20.

Criteria	Groups	Mean	SD	P
Union	Bur	1.00	0.00	>0.05
	Er:YAG Laser	1.00	0.00	
Spongiosa	Bur	1.85	0.89	>0.05
	Er:YAG Laser	1.85	1.06	
Bone Marrow	Bur	1.28	0.48	>0.05
	Er:YAG Laser	1.28	0.48	
Sum of Histologic Scores	Bur	4.14	1.06	>0.05
	Er:YAG Laser	4.14	1.46	

technique is better suited to minimally invasive surgical access which would facilitate the performance of an osteotomy. Lewandrowski et al.[15] suggested the pulsed Er:YAG laser appears to be an effective and precise bone ablator which is useful when the control of depth is required, as the case during the reconstruction of midface fractures in the infraorbital and sinus regions.

De Mello et al.[6] compared the bone repair process after osteotomies performed either with the Er:YAG laser or low-speed bur drilling in rat tibia. They reported the histological analysis of the control group (bur drilling) showed immature trabecular bone with smaller marrow cavities than those observed in the experimental group (Er:YAG laser). In addition, the histological analysis of the specimens in the group subjected to an Er:YAG laser ostectomy presented new immature trabecular bone which completely filled the bone cavity. However, through histological analysis at seven and 14 day intervals, De Mello et al.[6] demonstrated a Er:YAG laser experimental group presented more advanced bone repair than observed in the control group (bur drilling). Aoki et al.[16] examined the healing process of bone defects created by Er:YAG laser over the long-term in comparison with those created by a conventional rotating bur. They reported the Er:YAG laser was capable of ablating bone tissue with the same effectiveness as the bur treatment without causing severe thermal damage. These findings are consistent with the results of the present study which found no difference between the bur and Er:YAG laser groups in terms of bone healing at day ten post-surgery. There was not a significant difference among groups in the sum of histologic scores. Union, spongioza, and bone marrow were evaluated, respectively, and there was no significant difference between groups.

De Mello et al.[6] reported at 21 days after surgery the histological features of the bur and Er:YAG laser groups were very similar. They found the Er:YAG laser successfully promoted ablation of the bone tissue, removing the cortical bone and part of the medullar bone, and it was shown to be effective for the ostectomy procedure. The results of the present study were similar to De Mello et al.[6] because there was no statistically significant difference with regard to bone healing among the Er:YAG and bur groups at 20 days post-surgery in the rat specimens. There was no significant difference among groups in the sum of histologic scores, union, spongioza, and bone marrow at 20 days post-surgery.



Conclusions

Within the limits of this animal study, the Er:YAG laser was found to ablate bone effectively and precisely but required more time than steel surgical burs. No vibration during bone surgery when the laser was used compared to using steel burs. No difference was found between the Er:YAG laser and bur groups in terms of bone repair at ten and 20 days post-surgery.

Clinical Significance

Within the limits of this study a 2940 nm Er:YAG laser at 1.5 W can be used with confidence in cases requiring effective bone ablation. It has been found to be ideal for efficient bone ablation.

References

1. Frentzen M, Götz W, Ivanenko M, Afilal S, Werner M, Hering P. Osteotomy with 80-micros CO2 laser pulses histological results. Lasers Med Sci 2003; 18:119-124.
2. Buchelt M, Kutschera HP, Katterschafka T, Kiss H, Schneider B, Ullrich R. Erb:YAG and Hol:YAG laser ablation of meniscus and intervertebral discs. Lasers Surg Med. 1992; 12:375-381.
3. Buchelt M, Kutschera HP, Katterschafka T, Kiss H, Lang S, Beer R, Losert U. Erb:YAG and Hol:YAG laser osteotomy: the effect of laser ablation on bone healing. Lasers Surg Med 1994; 15:373-381.
4. Nuss RC, Fabian RL, Sarkar R, Puliafito CA. Infrared laser bone ablation. Lasers Surg Med

1988; 8:381-391.
5. 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.
6. de Mello ED, Pagnoncelli RM, Munin E, Filho MS, de Mello GP, Arisawa EA, de Oliveira MG. 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.
7. Stübinger S, Landes C, Seitz O, Sader R. Er:YAG laser osteotomy for intraoral bone grafting procedures: a case series with a fiber-optic delivery system. J Periodontol 2007; 78:2389-2394.
8. Stübinger S, Nuss K, Landes C, von Rechenberg B, Sader R. Harvesting of intraoral autogenous block grafts from the chin and ramus region: preliminary results with a variable square pulse Er:YAG laser. Lasers Surg Med 2008; 40:312-318.
9. Matsuyama T, Aoki A, Oda S, Yoneyama T, Ishikawa I. Effects of the Er:YAG laser irradiation on titanium implant materials and contaminated implant abutment surfaces. J Clin Laser Med Surg 2003; 21:7-17.
10. Stübinger S, von Rechenberg B, Zeilhofer HF, Sader R, Landes C. Er:YAG laser osteotomy for removal of impacted teeth: clinical comparison of two techniques. Lasers Surg Med 2007; 39:583-588.
11. Heiple KG, Goldberg VM, Powell AE, Bos GD, Zika JM. Biology of cancellous bone grafts. Orthop Clin North Am 1987; 18:179-185.
12. 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.
13. Pourzarandian A, Watanabe H, Aoki A, Ichinose S, Sasaki KM, Nitta H, Ishikawa I. Histological and TEM examination of early stages of bone healing after Er:YAG laser irradiation. Photomed Laser Surg 2004; 22:342-350.
14. Papadaki M, Doukas A, Farinelli WA, Kaban L, Troulis M. Vertical ramus osteotomy with Er:YAG laser: a feasibility study. Int J Oral Maxillofac Surg 2007; 36:1193-1197.
15. 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.
16. Aoki A, Yoshino T, Akiyama F, Miura M, Kinoshita A, Oda S, Watanabe H, Ishikawa I. Comparative study of Er:YAG laser and rotating bur for bone ablation. International Congress Series 2003; 1248:389-391.

About the Authors

Utkan Kamil Akyol, PhD
(Corresponding Author)

Dr. Akyol is a Research Assistant in the Department of Oral and Maxillofacial Surgery of the Faculty of Dentistry at Ataturk University in Erzurum, Turkey.

e-mail: utkanakyol@yahoo.com

Metin Güngörmüs, DDS, PhD

Dr. Güngörmüs is a Professor in the Department of Oral and Maxillofacial Surgery of the Faculty of Dentistry at Ataturk University in Erzurum, Turkey.

e-mail: gungormusm@yahoo.com

Cemal Gündogdu, DDS, PhD

Dr. Gündogdu is a Professor in the Department of Pathology of the Faculty of Medicine at Ataturk University in Erzurum, Turkey.

e-mail: cemalg@atauni.edu.tr

Havva Erdem, PhD

Dr. Erdem is a Research Assistant in the Department of Pathology of the Faculty of Medicine at Ataturk University in Erzurum, Turkey.

e-mail: drhavva@mynet.com

Acknowledgement

This study was supported by Ataturk University Scientific Research Projects Fund.