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Effect of Laser Pre-Drilling on Insertion Torque of Orthodontic Miniscrews: A Preliminary Study

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Purpose: To evaluate the effect of different-sized drill tips and laser irradiation times on the initial stability of orthodontic miniscrews placed in Er,Cr:YSGG-laser pre-drilled holes in an animal model.

Materials and Methods: Laser pre-drilled holes were made in dog mandibular bone with an Er,Cr:YSGG laser using irradiation times of 5, 7, 9, 11, and 13 seconds, and tip diameters of 0.4 and 0.6 mm. The maximum diameter and depth of the pre-drilled holes was measured with micro computed tomography. The maximum insertion torque was measured during placement the miniscrew.

Result: Laser pre-drilled holes were conical shaped. The maximum diameter of pre-drilled holes increased with longer laser irradiation times ($P>0.05$) and larger tip diameters ($P<0.05$). The depth of pre-drilled holes increased with longer laser irradiation times and larger tip diameters ($P<0.05$). When the 0.4 mm tip, but not the 0.6 mm tip, was used, the insertion torque decreased significantly with longer laser irradiation times ($P<0.05$).

Conclusion: Tip diameter impacted insertion torque more than irradiation time. It takes at least 9 seconds using a 0.6 mm tip to create a 0.8 mm diameter and 1.0 mm depth hole in thick cortical bone.

Key Words: Diameter; Er,Cr:YSGG-laser; Insertion torque; Irradiation time; Laser pre-drilling; Miniscrews

Introduction

Anchorage control is an important element for successful orthodontic treatment. The recent development of miniscrews as orthodontic anchorages has made tooth movement possible with minimal side effects, and does not require patients to comply with care procedures. Miniscrews have many advantages in comparison with other skeletal anchorages such as dental implants or miniplates; these include simpler

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placement and removal, minimal anatomical limitations at the placement site, a small size that causes less patient discomfort, and lower cost.

There are two types of miniscrews in orthodontics; self-tapping miniscrews, which require a pilot hole to be drilled before placement, and self-drilling miniscrews, which can be placed without pre-drilling. To increase the success rate of miniscrews, placement methods and miniscrew designs have been highly studied[1-5]. According to the results of these studies, self-drilling miniscrews appear to have better initial stability than self-tapping miniscrews and these are used more frequently[1-3]. However, self-drilling miniscrews placed in thick cortical bone (*e.g.*, mandible) without pre-drilling can cause bone resorption by bending or microfractures in the adjacent bone, which are caused by the torsional stress generated during miniscrew placement. Other risk factors include miniscrew slippage caused by the steep placement angle, injury to a dental root, or an undesirable placement direction because of difficulty in maintaining a fixed placement direction because of wobbling. In these situations, pre-drilling may be required, even for a self-drilling miniscrew.

Recently, the clinical application of lasers has increased in both dentistry and medicine. Among the lasers used, the Er,Cr:YSGG laser has a 2.78-μm wavelength and the absorption ratio to tissue (especially tissue with a high water content) is high so it can cut through both soft and hard tissue efficiently. It can also minimize thermal damage and carbonization to the surrounding tissue[6]. Thus, lasers can be used effectively under pertinent irradiation conditions to pre-drill holes for miniscrews in a dental clinic.

The purpose of this study was to examine the pattern, depth, and diameter of pre-drilled holes based on different irradiation times and tip diameters, and to evaluate the initial stability of the miniscrew after laser pre-drilling by analyzing the insertion torque in an animal bone model.

Materials and Methods

This study was designed for a healthy, adult, male beagle dog weighing 10 to 13 kg. Purchase, selection, management, and experimental surgical methods for laboratory animals were under the provisions of the animal testing and laboratory animal committee at Yonsei University Medical Research Center. The pre-drilled holes were made with a Waterlase MD (Biolase® Technology, Inc., San Clemente, CA, USA). The Waterlase MD has a 2.78-μm wavelength like any other Er,Cr:YSGG laser. Pulse duration, repetition rate, power, and injection amounts of water and air can be adjusted to various clinical applications as required.

A total of 21 cylindrical self-drilling miniscrews (OAS-1507C; Biomaterials Korea Inc., Seoul, Korea) were used. The miniscrews had a 1.5 mm external diameter and were 7 mm in length.

1. Laser Pre-Drilling Procedure

All experiments were performed on the mandibular bone of beagle dogs where, as in many clinical situations, pre-drilling through the thick cortical bone of the mandible is needed. After sacrificing the animal, the mandible was cut into the bone block, which included the third premolar to the first molar, a length of about 4 cm. After removal of the soft tissue including the periosteum, a pre-drilled hole was made at the surface of the bone block. The pre-drilled holes were formed at 3-mm intervals in the 1b mode (power 5.25 W, water 60%, air 65%) with the Waterlase MD. The laser beam was position vertically to the surface of the bone, and the head position of the handpiece was fixed about 0.5 mm from the surface of the bone. During formation of the pre-drilled holes, the power was kept uniform and the holes were divided into 10 groups according to the laser irradiation time (5, 7, 9, 11, or 13 seconds) and tip diameter (0.4 or 0.6 mm). The irradiation time was measured with a stopwatch and the distance between the tip and the bone was kept the same at 9 mm. Five pre-drilled holes were included in each group.

2. Morphometric Measurements With Micro Computed Tomography (CT)

Micro computed tomographic images of the bone block containing pre-drilled holes were acquired with a Skyscan micro CT 1076 (Skyscan, Kontich, Belgium; 18-μm resolution, Al 0.5-mm filter, 100 kV, 100 μA). The maximum diameter and depth of the holes was measured with the micro CT in μm since it used the Data Viewer Version 1.3.2 (Skyscan) program, and all measurement values were calculated as averages after having been measured two times.

3. Orthodontic Miniscrew Placement and Insertion Torque Measurements

In the control group, 3 miniscrews were placed without using pre-drilled holes. In the experimental groups, 3 miniscrews were included in each of six groups (18 miniscrews total). These were placed in randomly-selected laser pre-drilled holes drilled with the 0.4-mm or 0.6-mm tip and with laser irradiation times of 5, 9, or 13 seconds. All miniscrews were placed under saline irrigation. After placement, a periodontal probe was used to check the thread of each miniscrew to determine whether it went into the bone correctly. The maximum insertion torque was measured with a

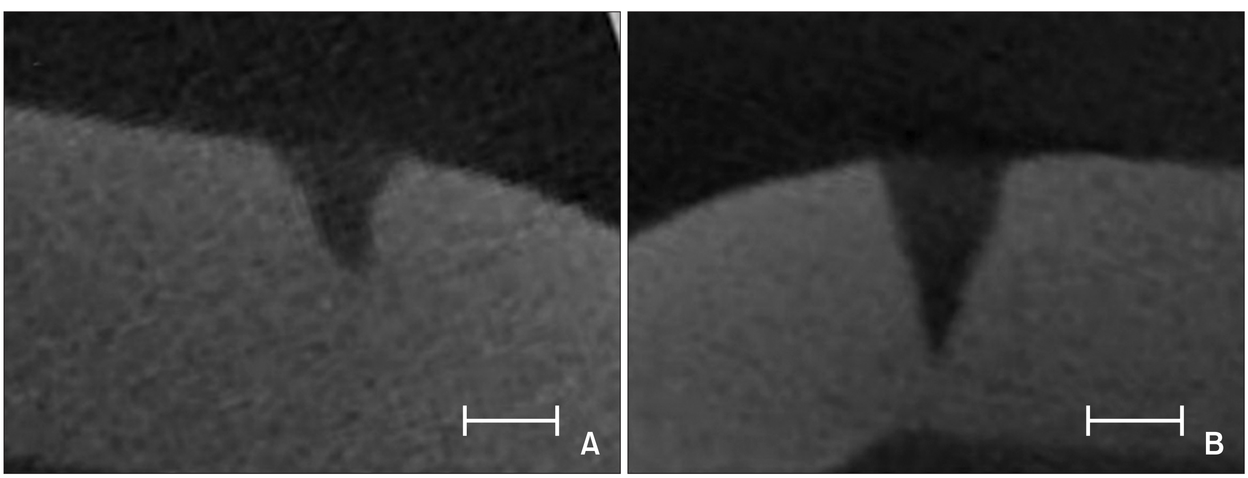

Fig. 1. Micro computed tomography image of laser pre-drilled holes. Scale bars=500 μm. (A) Tip=0.4 mm, irradiation time=9 seconds. (B) Tip=0.6 mm, irradiation time=9 seconds.

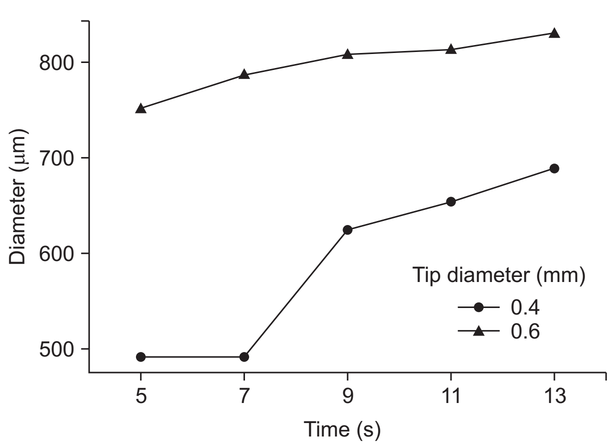

Fig. 2. Change in pre-drilled hole diameter with increasing laser irradiation times using the 0.4 mm and 0.6 mm tips.

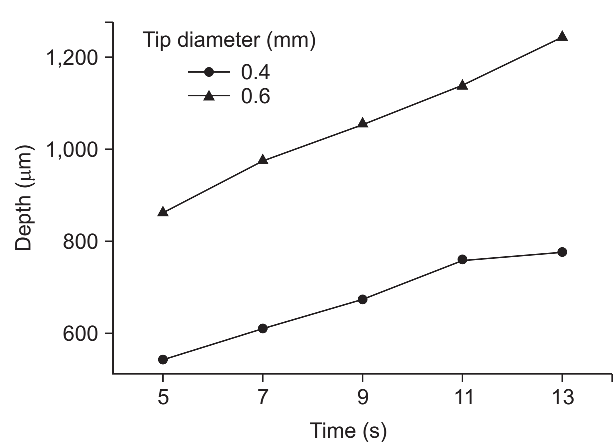

Fig. 3. Change in the pre-drilled hole depth with increasing laser irradiation times using the 0.4 mm and 0.6 mm tips.

torque sensor (MGT50; Mark-10, Copiague, NY, USA) in N·cm.

4. Statistical Analysis

For statistical analysis, SPSS Statistics ver. 12.0 (SPSS Inc., Chicago, IL, USA) was used. The Shapiro-Wilk test was used to verify the normality of data distribution. One-way analysis of variance (ANOVA) was used to compare the maximum diameter, depth of the pre-drilled holes, and insertion torque depending on the laser irradiation time after calculating the average and standard deviation. An independent t-test was performed to compare the maximum diameter, depth of the pre-drilled holes, and insertion torque depending on tip diameter.

Result

Laser pre-drilled holes were conical shaped (Fig. 1). The maximum diameter and depth of the pre-drilled holes increased with longer laser irradiation times and larger tip diameter (Fig. 2, 3). The maximum diameter of the pre-drilled hole increased with longer laser irradiation times when the same tip diameter was used, but the difference was not statistically significant. However, the depth of the pre-drilled hole increased significantly with longer laser irradiation times (P<0.05) (Table 1).

The maximum diameter of the pre-drilled hole was larger when the 0.6-mm tip was used than when the 0.4-mm tip was used regardless of the laser irradiation time, except when applied for 13 seconds. Also, the depth of the pre-drilled hole was deeper when the 0.6-mm tip was used than when the 0.4-mm tip was used regardless of the laser irradiation time (Table 2).

The insertion torque results for the control and experimental groups are illustrated in Fig. 4, 5. All the experimental groups required less insertion torque compared with the control group where the miniscrews were placed (Table 3).

When the 0.4-mm tip was used, the insertion torque decreased significantly with longer laser

Table 1. Comparison of the diameter and depth of the pre-drilled hole according to laser irradiation time when the 0.4-mm or 0.6-mm tip was used

Tip diameter (mm)	Time (s)	Diameter (μm)	Depth (μm)
0.4	5	489.9±58.3	539.6[b]±84.8
	7	489.9±88.4	610.5[ab]±104.8
	9	624.8±95.9	674.5[ab]±132.8
	11	653.2±99.1	759.7[ab]±119.3
	13	692.3±169.2	781.0[a]±166.5
	Sig.	NS	*
0.6	5	752.5±46.3	866.1[c]±143.4
	7	788.1±95.3	979.7[bc]±134.1
	9	809.4±58.3	1,057.9[b]±77.0
	11	813.7±97.5	1,143.1[ab]±46.3
	13	830.7±19.4	1,249.7[a]±68.2
	Sig.	NS	*

Sig.: significance, NS: not significant.
Values are presented as mean±standard deviation.
Significant difference was determined with the Tukey test.
*P<0.05.
[a,b,c]The same superscripts indicate no statistically significant difference between the indicated groups (P>0.05).

Table 2. Comparison of diameter and depth of the pre-drilled hole by tip diameter according to each laser irradiation time

Time (s)	Variable	Tip diameter (mm)		Sig.
		0.4	0.6	
5	Diameter (μm)	489.9±58.3	752.5±46.3	*
	Depth (μm)	539.6±84.8	866.1±143.4	*
7	Diameter (μm)	489.9±88.4	788.1±95.3	*
	Depth (μm)	610.5±104.8	979.7±134.1	*
9	Diameter (μm)	624.8±95.9	809.4±58.3	*
	Depth (μm)	674.5±132.8	1,057.9±77.0	*
11	Diameter (μm)	653.2±99.1	813.7±97.5	*
	Depth (μm)	759.7±119.3	1,143.1±46.3	*
13	Diameter (μm)	692.3±169.2	830.7±19.4	NS
	Depth (μm)	781.0±166.5	1,249.7±68.2	*

Sig.: significance, NS: not significant.
Values are presented as mean±standard deviation.
Significant difference was determined with the Tukey test.
*P<0.05.

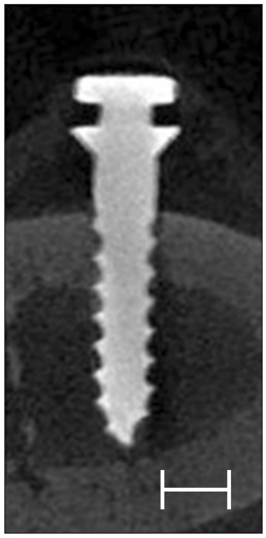

Fig. 4. Micro computed tomography image of a miniscrew place in a laser pre-drilled hole. Scale bar=200 μm.

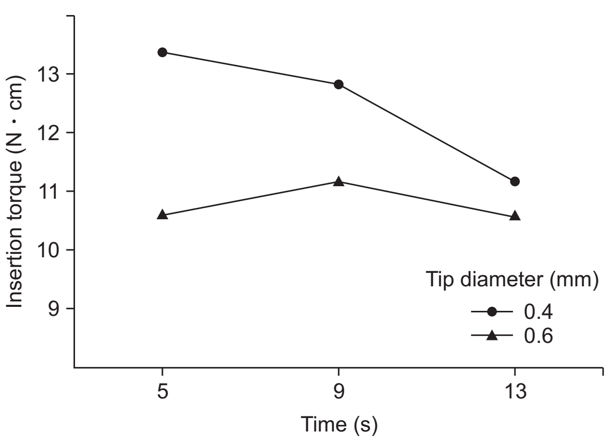

Fig. 5. Change in the insertion torque with increasing laser irradiation times using the 0.4 mm and 0.6 mm tips.

Table 3. Comparison of the insertion torque according to the laser irradiation times using two different tips

Tip diameter (mm)	Time (s)	Insertion torque (N·cm)
No drilling		15.5^{c}±1.44
0.4	5	13.4^{bc}±0.52
	9	12.8^{ab}±0.49
	13	11.2^{a}±0.33
	Sig.	*
0.6	5	10.6±0.63
	9	11.2±0.44
	13	10.4±0.40
	Sig.	NS

Sig.: significance, NS: not significant.
Values are presented as mean±standard deviation.
Significant difference was determined with the Tukey test.
*P<0.05.
[a,b,c]The same superscripts indicate no statistically significant difference between the indicated group (P>0.05).

Table 4. Comparison of the insertion torque according to the tip diameter at different laser irradiation times

Time (s)	Variable	Tip diameter (mm)		Sig.
		0.4	0.6	
5	Insertion torque (N cm)	13.4±0.52	10.6±0.63	*
9	Insertion torque (N cm)	12.8±0.49	11.2±0.44	*
13	Insertion torque (N cm)	11.2±0.33	10.4±0.40	NS

Sig.: significance, NS: not significant.
Values are presented as mean±standard deviation.
Significant difference was determined with the Tukey test.
*P<0.05.

irradiation times (P<0.05). When the 0.6-mm tip was used, the insertion torque decreased significantly compared with the control group (P<0.05), but there were no significant differences between different irradiation times.

When the 0.6-mm tip was used, the insertion torque was lower than when the 0.4-mm tip was used at all laser irradiation times, but there was no statistically significant difference between these two groups when the irradiation time was 13 seconds (Table 4).

Discussion

The Waterlase MD used in this study is an Er,Cr:YSGG laser, and its active medium is erbium, chromium, yttrium, scandium, gallium and garnet (solid). It has 2.78-μm wavelength. The main mechanism of tissue removal involves laser energy absorption by tiny water droplets sprayed on the surrounding sapphire or zirconium tip that results in a micro-explosion that induces a powerful mechanical force on the tissue surface. By using this power, tissue can be removed quickly and evenly.

In this study, pre-drilled holes were produced in the dog mandibular bone block with an Er,Cr:YSGG laser using different laser irradiation times and tip diameters. The pre-drilled holes were cone-shaped, narrowing to a point at the lowest depth, as shown by micro CT imaging. The diameter and depth of the pre-drilled holes tended to increase with larger tip diameter and longer laser irradiation times. The pre-drilled holes tended to get significantly deeper with increased laser irradiation times, and at least 9 seconds was required to form a hole 1.0 mm deep.

The range of compact bone thickness can vary depending on both the characteristics of the individual and the bone being used. According to the results of Kim et al.[7)] who recorded the thickness of the posterior soft tissue and compact bone in the maxilla of 23 Korean patients, the thickest region was located between the first and second premolar on the buccal side, 2 mm below the cemento-enamel junction, at a thickness of 1.55 mm. Deguchi et al.[8)] reported that the maxilla has a thickness of 1.8 to 2.0 mm on buccal alveolar bone. Also, the thickness of compact bone changed according to the insertion angle of the miniscrew. Summarizing the results of these studies, we can assume that the thickness of compact bone does not exceed 3 mm. In our study, the maximum thickness of the compact bone was 2.0 mm, and perforation of the compact bone was not always perfect under the established experimental conditions. However, the depth of about 1.2 mm for the pre-drilled hole, which occurred when the tissue was irradiated for 13 seconds and the 0.6-mm tip was used, is sufficient to prevent excessive stress when placing the self-drilling miniscrews used in our experiments.

The diameter of the pre-drilled hole showed no significant differences when used at the various irradiation times because the diameter of the tip was limited to a small range during the irradiation and the holes were conical shaped. The insertion torque of the miniscrews was affected most by the diameter of the pre-drilled hole, and this size should be smaller than the central diameter of the miniscrew.[9)] Heidemann et al.[10)] reported that enlarging the pilot hole to about 85% of the external diameter of the screw was suitable without compromising the holding power of the screw. In clinical applications, an unintentional enlargement of the pilot hole could occur because of wobbling during the drilling procedure. Therefore, it was recommended that a drill diameter greater than 80% of the screw external diameter not be used. This is in agreement with the 80% to 85% that Gantous and Phillips[11)] reported.

The largest diameter of the pre-drilled holes made in this study was about 1.0 mm, and was 67% of the diameter of the miniscrew used. We were unable to reach 80% of the diameter because the largest tip size used was 0.6 mm and the spot size of the laser is about 1 mm.

To increase the diameter or depth of a pre-drilled hole during laser pre-drilling, one can move the handpiece in a circle or place it closer to the bone as the depth of the hole deepens. However, the position of the handpiece was fixed vertically and horizontally in our study, but the handpiece could be moved toward the surface of the bone while irradiating to create a hole 1.2 mm in diameter and 1.8 mm deep using the 0.6-mm tip for an irradiation time of 13 seconds. The value clearly increased more than when irradiating from a fixed position, and a hole of about 80% of the miniscrew's diameter was achieved. But the reproducibility and predictability of a moving handpiece is poor; thus, to increase the diameter or depth of a hole, it is best to use a larger diameter tip or increase the irradiation time. However, as the irradiation time increases it is difficult to maintain a fixed position and thermal damage to the surrounding tissue could occur, so careful attention is needed.

Wang et al.[12)] observed morphological changes in bovine mandibular bone irradiated by an Er, Cr:YSGG laser. Using a fixed position of irradiation, the depth of the hole was greater in the contact group (4.43±0.49 mm) than in the non-contact group (2.81±0.33 mm). In the contact group, carbonization zones were found on the lower third of the hole, whereas minimum thermal damage was found in the non-contact group within a 10-μm thickness. In our study, the laser irradiation time was shorter and the tip was kept away from the surface of the bone such that thermal damage to the surrounding tissue was minimized.

Eriksson and Albrektsson[13] reported that 47°C for 1 minute is the threshold level for bone survival with increased temperatures. Kimura et al.[14] examined temperature changes when the Er,Cr:YSGG laser was used on mongrel dog mandibles at different irradiation times, reporting that the temperature increased 4°C after 10 seconds of irradiation, and to a maximum of 15°C after 30 seconds of irradiation. In our study, because the laser irradiation times were shorter and we did not let the tip contact the bone, thermal damage to bone, which is harmful to the stability of miniscrews, was not a problem. However, additional studies on the effects of the laser on the tissues through histologic analyses and long-term tissue reactions are needed. These kinds of studies could determine how longer irradiation times or contact of tip with bone affect the procedure to determine some of the clinical aspects of laser pre-drilling.

As expected, the insertion torque of the miniscrews when pre-drilled holes were used was about 67.1% to 86.5% lower than when pre-drilled holes were not used. When using the 0.6-mm tip at longer irradiation times, the insertion torque decreased even more, but the difference was not statistically significant. This is because the diameter of the hole, which has the most influence on the insertion torque, did not increase significantly with increased irradiation times. If the insertion torque is high, it may result in good initial stability, but excessive transformation and compression occurring at the bone-implant interface can cause congestion, necrosis at the bone-implant interface, or miniscrew fracture[15,16]. Motoyoshi et al.[17] recommended 5 to 10 N cm as an adequate insertion torque for self-tapping orthodontic miniscrews, and found an insertion torque of about 10 N cm when using 0.6-mm tips. Summarizing these results (maximum diameter and depth of a pre-drilled hole and insertion torque, etc.), pre-drilling should be performed over a minimum of 13 seconds with a 0.6-mm tip when placing the miniscrews used in this study. Also, it is necessary to select adequate tips and irradiation times for the type of miniscrew to be used and the thickness of the compact bone.

In this study, the shapes of the laser pre-drilled holes and the miniscrew insertion torque depended on the irradiation time and the tip diameter, and we found that pre-drilling decreased the insertion torque when inserting miniscrews in the thick compact bone of the mandible.

However, this study, as a preliminary study, was conducted on sacrificed beagle mandibles, a small sample size restricts the ability to extrapolate these findings to the general population. Additionally, to satisfy the normality of data distribution and to make sufficient number of trials, the pre-drilled holes were formed at intervals of 3 mm, but this could damage adjacent bone tissue. Therefore, histologic analyses of the tissue around laser pre-drilled holes are needed in *in vivo* studies, and should include more miniscrew factors so that long term stability and the torque required for removal as well as the insertion torque, mobility, etc. can be evaluated.

Conclusion

Tip diameter impacted insertion torque more than irradiation time. It takes at least 9 seconds using a 0.6 mm tip to create a 0.8 mm diameter and 1.0 mm depth hole in thick cortical bone. When inserting miniscrews after laser pre-drilling with an Er,Cr:YSGG laser, it is important to select the proper tip diameter and laser irradiation time according to the thickness of the cortical bone. The results of this study can be used as preliminary data in further detailed experiments on laser pre-drilling or corticotomy, etc., and can be used as reference data when applying lasers during clinical orthodontic treatments.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

References

1. Chen Y, Shin HI, Kyung HM. Biomechanical and histological comparison of self-drilling and self-tapping orthodontic microimplants in dogs. Am J Orthod Dentofacial Orthop. 2008; 133: 44-50.
2. Heidemann W, Terheyden H, Louis Gerlach K. Analysis of the osseous/metal interface of drill free screws and self-tapping screws. J Maxillofac Surg. 2001; 29: 69-74.
3. Kim JW, Ahn SJ, Chang YI. Histomorphometric and mechanical analyses of the drill-free screw as orthodontic anchorage. Am J Orthod Dentofacial Orthop. 2005; 128: 190-4.
4. Lee SY, Cha JY, Yoon TM, Park YC. The effect of loading time on the stability of mini-implant. Korean J Orthod. 2008; 38: 149-58.
5. Park HS, Jeong SH, Kwon OW. Factors affecting the clinical success of screw implants used as orthodontic anchorage. Am J Orthod Dentofacial Orthop. 2006; 130: 18-25.
6. 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: 21-7.
7. Kim HJ, Yun HS, Park HD, Kim DH, Park YC. Soft-tissue and cortical-bone thickness at orthodontic implant sites. Am J Orthod Dentofacial Orthop. 2006; 130: 177-82.
8. Deguchi T, Nasu M, Murakami K, Yabuuchi T, Kamioka H, Takano-Yamamoto T. Quantitative evaluation of cortical bone thickness with computed tomographic scanning for orthodontic implants. Am J Orthod Dentofacial Orthop. 2006; 129: 721.e7-12.
9. Okteno lu BT, Ferrara LA, Andalkar N, Ozer AF, Sario lu AC, Benzel EC. Effects of hole preparation on screw pullout resistance and insertional torque: a biomechanical study. J Neurosurg. 2001; 94(1 Suppl): 91-6.
10. Heidemann W, Gerlach KL, Gröbel KH, Köllner HG. Influence of different pilot hole sizes on torque measurements and pullout analysis of osteosynthesis screws. J Craniomaxillofac Surg. 1998; 26: 50-5.
11. Gantous A, Phillips JH. The effects of varying pilot hole size on the holding power of miniscrews and microscrews. Plast Reconstr Surg. 1995; 95: 1165-9.
12. Wang X, Ishizaki NT, Suzuki N, Kimura Y, Matsumoto K. Morphological changes of bovine mandibular bone irradiated by Er,Cr:YSGG laser: an in vitro study. J Clin Laser Med Surg. 2002; 20: 245-50.
13. 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: 101-7.
14. Kimura Y, Yu DG, Kinoshita J, Hossain M, Yokoyama K, Murakami Y, Nomura K, Takamura R, Matsumoto K. Effects of erbium, chromium:YSGG laser irradiation on root surface: morphological and atomic analytical studies. J Clin Laser Med Surg. 2001; 19: 69-72.
15. Meredith N. Assessment of implant stability as a prognostic determinant. Int J Prosthodont. 1998; 11: 491-501.
16. Ueda M, Matsuki M, Jacobsson M, Tjellström A. Relationship between insertion torque and removal torque analyzed in fresh temporal bone. Int J Oral Maxillofac Implants. 1991; 6: 442-7.
17. Motoyoshi M, Hirabayashi M, Uemura M, Shimizu N. Recommended placement torque when tightening an orthodontic mini-implant. Clin Oral Implants Res. 2006; 17: 109-14.