Biomechanical evaluation of the anodic oxidized miniscrew implant

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Biomechanical evaluation of the anodic oxidized miniscrew implant

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감사의 글

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ABSTRACT

Biomechanical evaluation of the anodic oxidized miniscrew implant

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The aim of this study was to evaluate biomechanical stability of orthodontic miniscrew which was surface treated with anodic oxidization method. In order to find out biomechanical stabilities depending on the time-points of the installation and also the biological characteristics of orthodontic miniscrew, the insertion torque, mobility and removal torque were measured by using anodic oxidized miniscrew and machined surface miniscrew. The surface form and surface roughness of each group were observed under SEM.

On each side of mandibular buccal bone in 6 mature dogs, 24 self-drilling type miniscrews of 1.45 mm diameter and 7 mm length were installed respectively. Then immediate loading was applied after the installation, and the success rate, insertion torque, mobility and removal torque were measured. Beagle dogs were sacrificed, and the tissue specimens were made and histological changes were compared and observed. The obtained results were as follows:

1. The overall success rate of total 48 miniscrews was 98%.
2. There was no statistically significant difference in insertion torque.

   The insertion torques were 12.5 Ncm in experimental group and 12.2 Ncm in control group ($P > 0.05$).
3. In mobility measurement, there was a statistically significant difference between the time-points of measurements ($P < 0.05$), but there was no statistically significant difference between groups at certain time-point ($P > 0.05$).

4. There was a statistically significant difference between groups in removal torque. The removal torques of experimental group were 4.1 Ncm in 3 weeks and 4.6 Ncm in 12 weeks, and the removal torques of control group were 2.4 Ncm in 3 weeks and 2.5 Ncm in 12 weeks (P <0.05).
5. In histological observation, anodic oxidized miniscrew group showed more mature bone adjacent to miniscrew as time passed.

In this study, anodic oxidized miniscrew showed a relatively higher osseo-integration ability than those of non-oxidized ones. This is thought to be helpful for the biocompatibility, and it is considered that various comparative studies will be necessary.

Key words : anodic oxidized miniscrew, mobility, insertion torque, removal torque.

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I. INTRODUCTION

An appropriate anchorage gaining is an important factor for the success of orthodontic treatment. Recently, orthodontic miniscrews have been used for orthodontic anchorage. It is clinically applied in various ways, because it can increase the effectiveness of orthodontic treatment with relatively easy placement and without patient's cooperation (Park and Kwon, 2004; Park, 2006a).

However, the use of orthodontic miniscrew does not always guarantee the success of treatment. And initial stability should be taken into consideration in order for miniscrew to be used for orthodontic anchorage. Clinical success rate of miniscrew in orthodontic treatment has reached up to 90 % which is remarkable in recent years. But, it has been reported that its failure rate has been shown to be approximately 10-15% (Tseng et al, 2006; Kim et al, 2008). Also, it is a fact that success rate of miniscrew is still lower than that of dental implant, and its prognosis is poorer as well. Failure of miniscrew not only can let down the prediction for treatment result but also can break the trust for the orthodontist. Therefore, studies on the methods for predicting treatment results and improving its stability would be needed.

Failure of miniscrew can be caused by complex external or internal factors. Lim et al (2009) suggested surgeon factor (clinical experience), patient factors (age, gender, maxilla or mandible, location of placement, tissue mobility) and miniscrew factors (length, diameter, shape). Cheng et al (2004) reported that miniscrews placed on the non-keratinized epithelial mucous membrane showed high failure rate. Buchter et al (2005) and Joes et al (2005) reported that duration and strength of the load also affected the stability. Miyawaki et al (2003) reported that whether there was an inflammation around miniscrew or not, and patient's mandibular plane angle could affect the stability of miniscrew. Okuyama et al (2000) reported that the factors of miniscrew were related to the design (diameter and length).

Orthodontic miniscrew sustains the initial load with the stability from the mechanical sustainability between bone and the surface of miniscrew (Umemori et al, 1999). Design of orthodontic miniscrew has been developed for initial fixation, and the initial stability of miniscrew is an important factor which can affect the success rate (Huja et al, 2005). Biomechanical stability of orthodontic miniscrew is important because it induces the healing process of the surrounding bone. Studies on surface treatment in orthodontic materials have been done, and the studies on bone bonding ability and stability have been done as well. It is reported that surface treatment for miniscrew could increase bone adhesion and could minimize the absorption of the surrounding bone. And, it could increase the bond strength and compatibility to the surrounding tissue. Therefore, various orthodontic miniscrews based on surface treated implants have been developed.

Oh et al (2006) reported that SLA(sandblasted, large-grit and acid etched) miniscrew showed a higher removal torque than that of machined surface miniscrew and it induced more bone bonding to orthodontic force resistance than machined surface miniscrew did. Habig et al (1990) introduced plasma ion planting method which increased the thickness of the coating and thus had a resistance against corrosion and abrasion. From the results of TiN coating experiments, they suggested that using ion planting method to dental metal could bring anti-abrasion resistance and mechanical advantages. Koh et al (2009) reported that although anodic oxidation and Ca-P coating increased initial stability and bond strength to the surrounding bone, they were not superior to the conventional SLA method.

Surface treatment of miniscrew affects the surface form and the surface roughness, and the increase of the surface area is closely related to the bonding between bone and miniscrew. In this study, the experiment was done using titanium miniscrew on which anodic oxidation surface treatment method was used. The surface of anodic oxidized miniscrew is composed of numerous open pores. It shows a higher osseointegration rate in primary healing due to a relatively larger surface area and better surface wetness because its surface is rougher than that of machined miniscrew (Choi, 2012).

During initial healing period, higher osseointegration of anodic oxidized implant is observed (Elias et al, 2008; Strnad et al, 2007). Boyan et al (1996) and Larsson et al (1996) explained that osteoblasts could more easily attach to a rough surface than to a smooth surface.

Anodic oxidation method requires a high voltage on electrolyte and it forms an oxide layer on the surface of implant. As a result, rough surface with more porosities is formed and chemical composition improves biocompatibility. Incorporation of Ca^{2+} into anodic oxidized titanium surface induces osseointegration. The amount of Ca and P in the surface of the anodized oxide implant is higher than that in the machined surface implant (Choi et al, 2009; Choi et al, 2010).

In order to observe the surface of anodic oxidized miniscrew, scanning electron microscope (SEM) was used and the observation was done by comparing it with machined surface miniscrew. Each miniscrew was compared to one another under x50, x200 and x2000 magnification, and the surface roughness form and porous structure of anodic oxidized miniscrew were observed. It is considered that higher bonding strength will be able to be gained as the surface area gets larger since the surface and the roughness directly affect the mechanical sustainability between bone and miniscrew because it is affected by the contact surface.

In order to observe initial stability before and after placing an anodic oxidized miniscrew, insertion torque, removal torque and mobility can be used. Insertion torque measurement means resistance force of an implant to bone surface, and shows the level of stress strain of the bone that is displaced by miniscrew. It is helpful for the prediction by being an indirect indication factor for density of surrounding bone. Cheng et al (2004) suggested the method of measuring an insertion torque of miniscrew for the evaluation of initial stability, and reported that an insertion torque higher than a certain level was necessary to obtain initial stability. Motoyoshi et al (2006) has reported that excessively strong insertion torque can actually action unfavorably to the stability of miniscrew suggesting 5-10 Ncm as an appropriate insertion torque of self-tapping type orthodontic miniscrew.

Removal torque measurement was used for the assessment of the osseointegration between bone and miniscrew (Simon et al, 2002). Johansson and Albrektsson (1987) reported that bone contact area and removal torque increase in proportion to time, and suggested that bone contact area and removal torque were highly related to each other.

Periotest value was used for evaluating the stability of miniscrew in this experiment because it is easy to use, and mobility test can be done continuously even after the insertion (Schulte, 1992).

The aim of this study is to evaluate the biomechanical characteristic of anodic oxidation miniscrew implant under self-drilling placement with machined surface miniscrew by measuring insertion torque, periotest value and removal torque and the effectiveness of clinical application.

II. MATERIAL AND METHODS

1. Experimental animals and material

In this study, miniscrews were placed to 6 Beagle dogs of 10 -13 kg body weight and 1 year of age. Their purchase, selection, management and experiment were carried out according to prescribed conditions of the institutional review board, the Animal Experimental Committee of Yonsei Hospital, Seoul, Korea.

A self-drilling type miniscrew, 1.5 mm in diameter and 7 mm in length, was used (Diameter of anodic oxidized miniscrew was 30-40 μm larger than that of machined surface miniscrew). Both machined surface and anodic oxidized miniscrews were selected (Biomaterials Korea, Seoul, Korea) (Fig 1). 48 miniscrews in total were used. The roughness of anodic oxide layer of titanium was obtained from electrolyte including calcium acetate and ß-calcium glycerophosphate at 250V.

Fig 1. Miniscrews used on experiment.

(left, machined surface; right, anodic oxidized)

2. Methods

A. Scanning electron microscopy (SEM) observation

In order to observe the surface of miniscrew, each group was processed for scanning electron microscopy (SEM). They were examined and photographed with SEM (Hitachi, Tokyo, Japan) at the acceleration voltage of 20kV, by x50, x200, x2000 magnification.

B. Insertion and removal of orthodontic miniscrews

Atropine 0.05 mg/kg was subcutaneously injected to the experimental animal, and Rompun 2mg/kg and Ketamine 10mg/kg were intravenously injected and then general anesthesia was induced with the anesthesia being maintained with 2% Enflurane and with the body temperature being maintained with heating pad during the experiment. Infiltration anesthesia with 2% hydrochloric acid lidocaine including epinephrine (1:100,000) was done as well on the insertion site when inserting miniscrew. Gingival incision was done on the gingiva before the insertion, and whether the threads of miniscrew were completely embedded in the alveolar bone or not was checked with saline being irrigated.

Horizontal and vertical position of the insertion site for miniscrew was decided after accessibility to the root of tooth was checked. The position was decided to be in-between the roots of 2^{nd}, 3^{th} and 4^{th} premolar and 1^{st} molar in mandible. Insertion site for anodic oxidized miniscrew to the same mandibular quadrant was decided to b-2-2e in-between the roots of the 2nd and 4th premolar, and insertion site for machined surface miniscrew was decided to be in-between the roots of 3rd premolar and 1st molar (Fig 2).

Miniscrew was manually inserted at an angle of 90˚ to gingival surface with the buccolingual width being considered. Right after the insertion, orthodontic forces ranging from 250 mg to 300 mg were applied to each miniscrew using NiTi coil springs. Orthodontic forces were applied for 3 weeks and for 12 weeks. The maximum insertion torque was measured in Ncm using torque sensor (MGT50, Mark-10, USA), and mobility was measured after the insertion using mobility testing device (Periotest, Simens, Germany) (Fig 3). Mobility measurements were done twice, and chlorohexidine mouth wash was carried out during the experiment period for the animal’s oral hygiene. Miniscrews of 3 weeks loading group and 12 weeks loading group were simultaneously removed after measuring the mobility of miniscrews in 12 weeks, and removal torques were measured.

Fig 2. Implantation sites of orthodontic miniscrews. An orthodontic force was loaded reciprocally between an anodic oxidized miniscrew and a machined surface miniscrew. The force-applied groups were reciprocally using Ni-Ti coil spring (250-300gm).

Fig 3. Test devices. (left, MGT50; right, Periotest)

C. Histological observation

After euthanizing the test animals, using a low-speed diamond wheel, in the center of each miniscrew, a notch was formed. Afterwards, a block of tissue that included a miniscrew was collected, and it was held firmly in a 10% formalin solution for 1 month. After tissue fixation, we dehydrated the specimen with high density alcohol for 14 days, embedded it polymethylmethacylate and cured it in a vaccum. We prepared specimen with 100-110 μm thickness using the hard tissue grinding system and conducted H-E stain. We used optical microscopy by x50 and x100 magnification for histological observation. In 3 weeks and in 12 weeks, histological change pattern of miniscrews of each group and surrounding bones were examined.

D. Statistical analysis

SAS program (SAS Inc., Cary, NC, USA) was used for overall statistical analysis. The mean value and standard deviation for insertion torque, removal torque and periotest value of machined surface miniscrew and anodic oxidized miniscrew were calculated by independent t–test. Bonferroni test was done as post-hoc test for mobility of each time-points after 2-way ANOVA test. P-values less than 0.05 were regarded as statistically significant.

III. RESULTS

1. Success rate of miniscrew

The success rate depending on the methods of placement were 95.8% in machined surface miniscrew group and 100% in anodic oxidized miniscrew group. The overall success rate was 98% and there was one machined surface miniscrew with failure.

2. Scanning electron microscopy(SEM) image of miniscrews

Miniscrews were scanned at 50, 200 and 2000 times magnification for surface properties. Anodic oxidized miniscrew showed more rough surface compared with machined surface miniscrew (Fig 4).

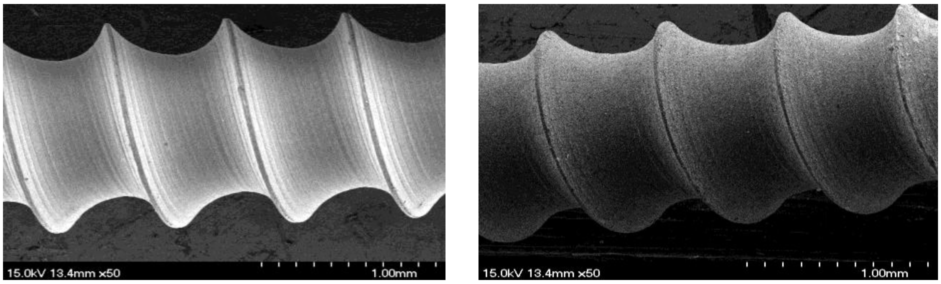

Fig 4. Comparison of SEM image (x50).

(left, machined surface; right, anodic oxidized)

Machined surface miniscrew had an appearance of streaks on the surface that were made during the production process. Machining lines were relatively regular and had constant directions. Anodic oxidized miniscrew showed more rough surface. There were different micro porous structures on the oxidized surface. Dense oxide layer with porosities increase the surface area which contacts bone (Fig 5).

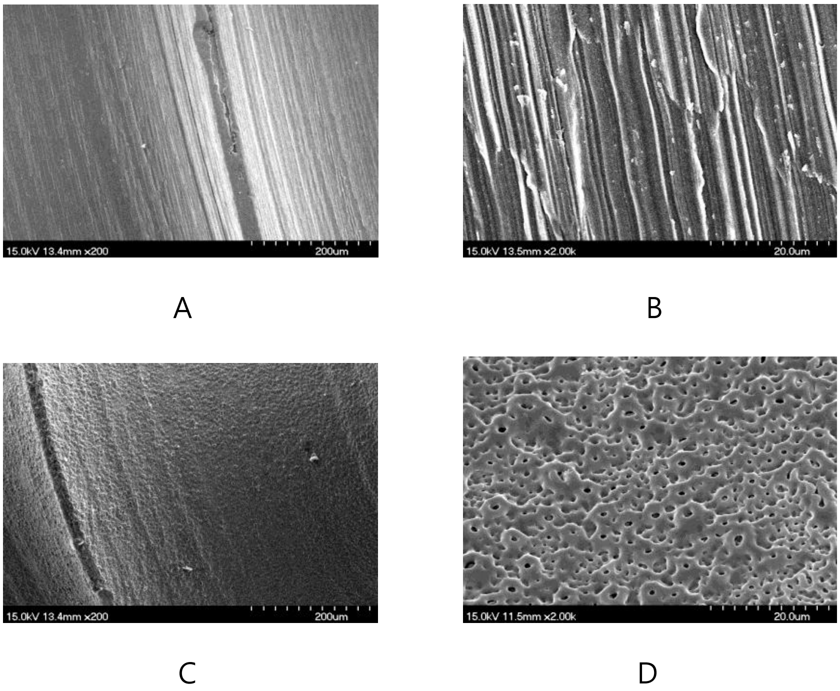

Fig 5. Scanned images of miniscrews (left, x200; right, x2000).

A, B, machined surface miniscrew ; C,D, anodic oxidized miniscrew.

3. Measurement of insertion torque

Anodic oxidized (AO) miniscrew group showed a little higher insertion torque value of 12.5 Ncm compared with the value of 12.2 Ncm of machined surface (MS) miniscrew group. But, there was no significant difference (P >0.05) (Table 1).

Table 1. Comparison of insertion torque between MS and OA groups.

Variable	Insertion torque (Ncm)	
	Mean	SD
MS	12.2	4.61
AO	12.5	4.80

MS, machined surface miniscrew; AO, anodic oxidized surface miniscrew;

SD, standard deviation

4. Measurement of periotest value (PTV)

The periotest value were lowest on placement of miniscrews in each group. There was significant differences as time passed between AO and MS groups (P <0.05). Anodic oxidized (AO) miniscrew group showed lower periotest value compared with machined surface (MO) miniscrew group. But, there was no significant difference (P >0.05) (Fig 6, Table 2).

Table 2. Mobility change for loading periods (Periotest value)

Weeks	0		3		6		9		12	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
MS	1.91	3.88	6.76	6.50	8.98	5.64	10.0	5.20	5.47	5.37
AO	1.58	3.93	5.80	6.81	6.73	4.95	7.65	5.37	6.25	4.95

MS, machined surface miniscrew; AO, anodic oxidized surface miniscrew

SD, standard deviation.

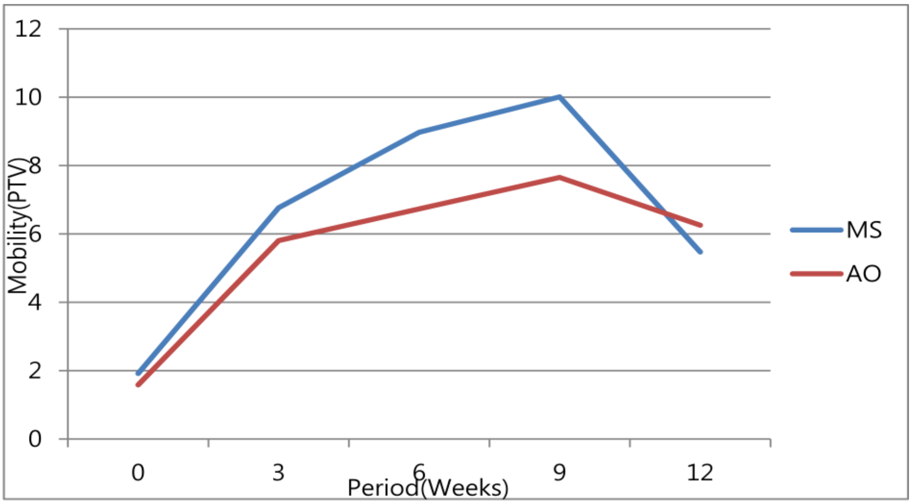

Fig 6. The periotest value. No significant difference was found between AO and MS groups by independent *t*-test (P >0.05). There were significant differences over time (P <0.05). (MS, machined surface miniscrew; AO, anodic oxidized surface miniscrew).

5. Measurement of removal torque

There were significant differences between AO and MS groups in 3 weeks and in 12 weeks (*P* <0.05). But, no significant differences were found between each inter-groups in 3 weeks and in 12 weeks(*P* <0.05).

Table 3. Comparison of removal torque between MS and OA groups

Variable	Removal torque (Ncm)			
	3 week		12 week	
	Mean	SD	Mean	SD
MS	2.4	1.04	2.5	1.69
AO	4.1	1.80	4.6	2.24
Sig.	*		*	

MS, machined surface miniscrew; AO, anodic oxidized surface miniscrew

SD, standard deviation; Sig, significance.

6. Histological observation

By respectively choosing 1 pair of miniscrew from both 3 weeks group and 12 weeks group where removal torque was not measured for examining the histological features, three weeks later, anodic oxidation miniscrew group and machined surface miniscrew group showed a little cortical bone adjacent to miniscrew. And, a new bone seemed to be already mature enough to sustain initial loading (Fig 7).

After 12 weeks, adjacent bone is already mature enough to develop into bone. Anodic oxidized miniscrew group showed more mature bone adjacent to miniscrew compared with machined surface miniscrew group (Fig 8).

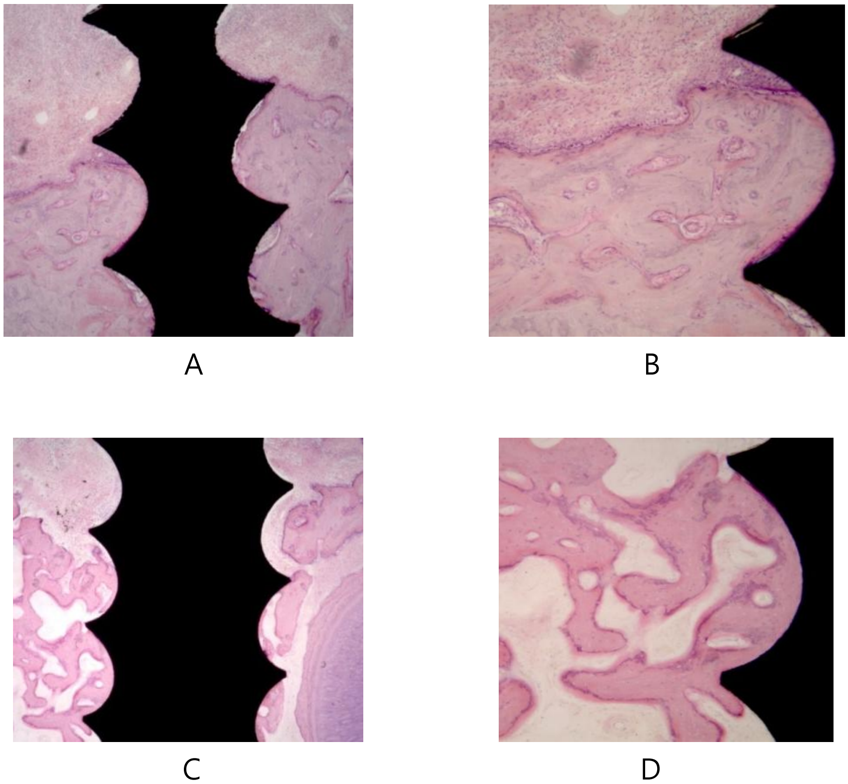

Fig 7. Comparison of miniscrews at 3 weeks. H-E staining(left,x50; right,x100);

A, B, machined surface miniscrew ; C,D, anodic oxidized miniscrew.

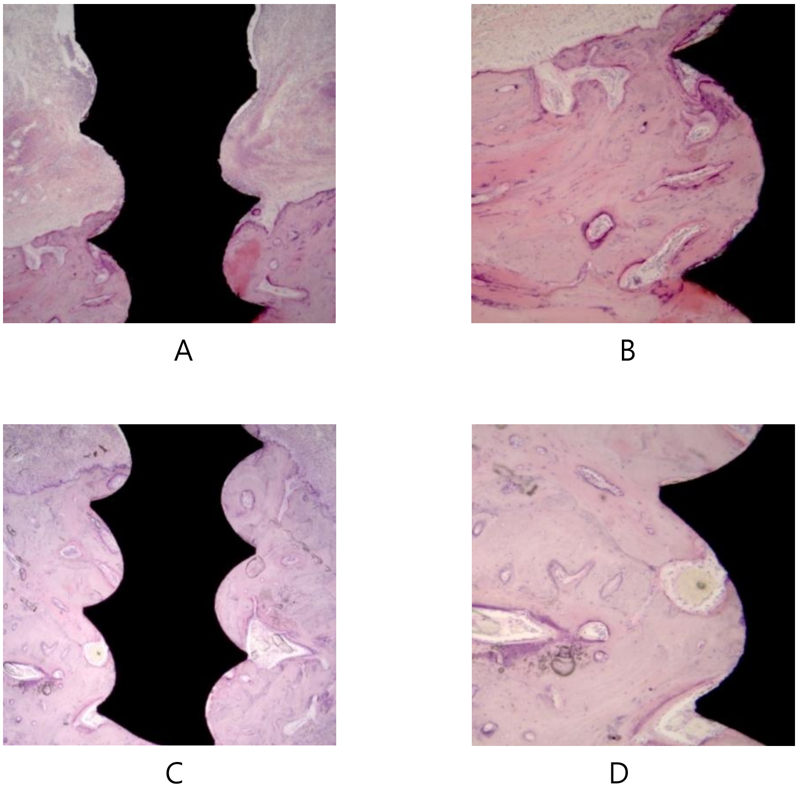

Fig 8. Comparison of miniscrews at 12 weeks. H-E staining(left,x50; right,x100);

A, B, machined surface miniscrew ; C,D, anodic oxidized miniscrew.

IV. DISCUSSION

In this study, to evaluate biological stability and clinical applicability of anodic oxidized miniscrews, direct measuring methods including measurement of insertion torque, removal torque and periotest value of orthodontic miniscrews were used. In addition, the surface of each miniscrew group was observed with SEM, and tissue specimens of osseous tissue around the miniscrew were observed.

Orthodontic miniscrews were initially developed with initial stability and convenient procedure based on the advantages of flexible placement area, simple procedure and immediate application of orthodontic force and low cost (Park et al Kwon, 2004; Park, 2006). There were reports that orthodontic miniscrew was mainly maintained by its mechanical retention and osseointegration was not absolutely needed. However, attempts to obtain a strong retention using miniscrews have been progressed continuously by many previous researchers (Lim et al, 2009). The previous studies were focused on the development of stable insertion method, design and diameter of miniscrew.

Yoon et al (2001) reported that if a miniscrew had a sufficient length when it was inserted, it would be stable. Lim et al (2003) reported that the larger the diameter of orthodontic miniscrew was, the stronger the retentive force became, because the retention of miniscrew was more closely related to its diameter. Huja et al (2005) suggested that initial stability was an important factor which affected the success rate during the treatment time, and the thicker the cortical bone into which miniscrews are inserted, the higher pull-out strength are made. Joe et al (2003), in their comparative study between the immediate application group and the delayed application group using mature dogs, suggested that osseointegration also occurred in smooth surface mini implant. Park et al (2006) reported that existence of inflammation around the miniscrew affected the stability of miniscrew.

Modifying the design of miniscrew could increase the initial fixation, and Cha et al (2006) reported that the cone-shaped miniscrew could increase the insertion torque significantly. The mobility of miniscrew decreased due to a tight contact of miniscrew into bone because miniscrew modified the surrounding bone. Also, cone-shaped miniscrew had an advantage in its initial stability compared with cylindrical miniscrew, and design of the screw thread to increase the mechanical bond was mentioned as well. Chen et al (2008) reported that self-drilling miniscrew showed a higher stability than that of self-tapping miniscrew. It used to be believed that miniscrew was only maintained by its mechanical bonding, and that surface treatment was not done in most of the previous experiments.

Recently, an emphasis has been shifted to bone bonding ability and stability for initial fixation. In the studies on prosthetic implant reported by Lim et al (2001), the group in which conventional surface treatment was done showed a higher bond strength than the group in which no surface treatment was done. Machined surfaced miniscrew on which no surface treatment was done has been used where the force applied on tooth is relatively weaker than that on prosthetic implant. However, there has been some experiment reports on surface-treated miniscrew because there was a limitation in the resistance against the falling of orthodontic mini implant or against the force applied in various directions (Lim, 2003).

It was proved that structure of mini implant and surface treatment were important factors for a successful osseointegration, and there have been many studies on the increase of surface roughness. For surface treatment methods for mini implants, titanium plasma spray, acid prickling, acid etching, sandblasting, anodic oxidization and so on have been tried. Jung et al (2004) introduced an orthodontic mini implant of which osseointegration ability was improved by SLA(sandblasted, large-grit and acid etched) surface treatment, and Oh et al (2006) reported, through their mechanical study on orthodontic mini implant using rabbit, that SLA surface treated mini implant showed a significantly higher removal torque than that of machined surface mini implant, and they evaluated that it should be due to the difference of the bone bonding ability against orthodontic force. Kim et al (2008) reported that an SLA mini implant showed a high removal torque, and it increased the stability to dynamic orthodontic force. Habig (1990) introduced a plasma ion planting method and they suggested that it increased the thickness of the coating and thus improved the resistance against corrosion and abrasion and could change the color of the surface fast. Koh et al (2009) reported that although anodic oxidation and Ca-P coating increased the stability and the bonding strength to the surrounding bone, they were not superior to the conventional SLA method. On the other hand, some researchers reported that abundant calcium and phosphorus of anodized surface layer promoted chemical bonding of implant to bone and increased the twisting strength of bone and anodized miniscrew. Based on the fact that osseointegration of mini implant can be improved by doing the surface treatments, there was a recent study report that anodic oxdized titanium miniscrew raised oseeointegration ability of miniscrew (Jang, 2011). If a sufficient osseointegration occurs through surface treatment of titanium miniscrew, an anchorage which can resist against rotational force and orthopedic force of jaw bone for which a bigger force than orthodontic force is required generally can be provided. Also, the range of orthodontic treatment procedure can be expanded because the failure rate is lowered and the retention is improved. The effectiveness of the surface treatment of miniscrew seems to be related to biocompatibility of bone. Anodized surface layer looks more porous and uneven (Choi, 2012). Micro-fine irregularity forms a less even stress structure, and it induces differential bone remodeling and increases mechanical bonding of miniscrew to bone and produces a higher removal torque. In spite of various efforts for the search for a stronger retention and also the reports that surface treated orthodontic miniscrew maintains a stability during treatment as well clinically, studies on the measurement of mobility or the comparative studies on removal torque of miniscrews were not extensively done.

As non-invasive evaluation methods for the stability of implant clinically, there are Osstell which is a commercialized system of resonance frequency measurement and Periotest in which the mobility of tooth is measured by measuring the degree of damping of periodontal ligament. In clinical application, Periotest method is widely used due to its cost-effectiveness and easy handling compared with other device (Schuite, 1992), and the same method was used in this experiment as well. Histological evaluation method, calculation of contact ratio between bone and implant, has been used usually, but in this experiment, the evaluation was done through measuring the removal torque.

Among 48 miniscrews which were implanted in normal position, there was one machined surface miniscrew with failure, and the success rate was 98%. It seems that the failure occurred due to an inflammation on the gingiva due to inappropriate plaque control of beagle dog.

Under x50, x200 and x200 magnification SEM view, the surface form and roughness of each miniscrews were observed. In machined surface miniscrew, parallel streaks which are believed to have been made by polishing process were seen on the smooth surface, and they were relatively regular and smooth surface form. On the surface of anodic oxidized miniscrew, micropores which were irregular and multiple-layered were evenly spread in oxide layer. It was reported that the surface and the roughness directly affected the mechanical sustainability of bonding between bone and implant and the stronger bonding could be gained as the surface area got larger because it was affected by the contact surface. (Larssen et al, 1996)

In 3weeks group and 12 weeks group, histological change of each groups were observed by using optical microscope. Looking into the findings of 3weeks groups, no particular inflammatory finding was shown in each groups, and the formation of new bone trabecules were shown. Looking into the findings of 12 week groups, anodic oxidized miniscrew group showed more increase of the mature compact bone. There was a report where it was said that micropores were formed on the surface of anodic oxidized implant and thus the bone contact area increased and primary attachment of myelocyte increased and also the differentiation into osteoblast and formation of bone matrix was induced and thus bone formation period could be shortened.

Cheng et al (2004) suggested measuring the insertion torque as a method with which the initial stability of orthodontic miniscrew could be evaluated, and they said that measurement of insertion torque could be used as primary indicator for the stability of implant in prosthetic implant and could reflect the mechanical property of implant (Homolka et al, 2002). In this study, the insertion torque of anodic oxidized orthodontic miniscrew was observed to be 12.5 Ncm compared with 12.2 Ncm of machined surface miniscrew. But, there was no significant difference between groups. And this value is higher than the experiment result of the previous study. It is considered that the reason why the insertion torque was measured higher than that of self-tapping type was because pilot drill was used in the previous study. Motoyosi et al (2006) reported that excessively strong insertion torque can actually action unfavorably to the stability of miniscrew and suggested 5-10 Ncm as an appropriate insertion torque of self-tapping type orthodontic miniscrew. Although it is difficult to define physiological torque range of human because there is no research targeting human on insertion torque of self drilling type, a similar result is shown in this experiement.

High insertion torque can be a good thing in terms of initial stability, but it also means that excessive modification of bone and compressive force are produced, and congestion and necrosis of bone surface or fracture of miniscrew can occur (Meredith 1998, Ueda et al, 1991). When insertion is done with self-drilling method, fracture of miniscrew can occur if cortical bone is hard or if implant contacts the root of tooth (Cheng et al, 2004; Buchter et al, 2005). In the case of self-tapping type miniscrew, drilling before insertion is an essential procedure because it has a shape for self tapping without cutting edge, the space between implant and bone can exist and this can be a disadvantage in the initial stability. To complement a disadvantage like this, an attempt to improve the fixation by reducing the diameter of drill can be made. However, it was said that there was a limitation in reducing the diameter because drill could be fractured, and early failure could occur by local ischemia if higher insertion torque was produced. On the contrary, the method in which the diameter of miniscrew is enlarged, root damage or failure can occur. The possibility of miniscrew to contact the root gets higher when it is inserted in-between the roots. If surface treatment is done to self drilling type miniscrew, there could an advantage of good initial stability because insertion can be done without drilling, but the shape of cutting edge part also can be changed during the surface treatment procedure and this can decrease the bone cutting ability possibly. As methods for doing surface treatment maintaining bone cutting ability and bone penetration ability of cutting edge part, the method in which maintaining the cutting edge part as a machined surface and doing surface treatment to the remaining part and also the method in which the general depth of surface treatment decreases just as in anodic oxidization method can be considered. In this study, insertion torque of each group was shown to be similar. Although insertion torque is used for the evaluation of initial stability of implant, it can only be measured during insertion, therefore continuous mobility measurement method is being introduced and its reliability and its clinical meaning are being reported.

Periotest® is an electronic device which was developed for the measurement of tooth and its value is shown by Periotest value (PTV), and it shows the range from -8(low mobility) to 50(high mobility). Periotest value was used for evaluating the stability of miniscrew in this experiment because it is easy to use, and it has an advantage that the mobility test can be done continuously even after the insertion. The results of mobility analysis were that the mobility of anodic oxidized miniscrew was 1.5 at the insertion which was lower than that of machined surface miniscrew by 1.9, and it increased gradually in

3weeks, 6weeks and 9 weeks in order. Periotest value had significant differences in time (*P* <0.05). But, no significant difference was shown between anodic oxidized miniscrew and machined surface miniscrew (*P* >0.05). It was shown that the mobility of surface treatment group was a little favorable than that of non surface treatment group until 12 weeks. As time progressed, flow pattern of the groups became similar to one another. However, measurement of mobility cannot reflect the absolute value because various diameters and lengths of miniscrew are used. For example, as diameter of implant gets larger, mobility of implant gets lower. It is thought that measurement of mobility will be effective as comparative and indirect evaluations between two groups in the area where bone density is high and cortical bone is thick.

Physical measuring method of removal torque is effective to check the degree of osseointegration between bone and implant. Through a histological observation, Johansson and Albreksson (1987) reported that the surface area of bone and implant and removal torque increase in proportion to the elapsed time, and these two factors had a very close correlation to each other. Removal torque is affected not only by the elapsed time but also by the diameter of implant, chemical composition of the surface and micro-structure of the surface. Besides, there has been a study of which the result was that osseointegration ability and resistance to removal torque increased when SLA surface treatment to mini implant was done. Recently, it has been reported that surface treatment through anodic oxidization shows better stability (Jang, 2011).

In this study, removal torque of anodic oxidized miniscrew was 4.1 Ncm in 3 weeks and 4.6 Ncm in 12 weeks. And, removal torque of machined surface miniscrew was 2.4 Ncm in 3 weeks and 2.5 Ncm in 12 weeks. There was significant differences between anodic oxidized miniscrew and machined surface miniscrew in 3 weeks and in 12 weeks ($P < 0.05$). But, no significant difference was found in each inter-groups in 3 weeks and in 12 weeks ($P > 0.05$). This value is lower than 14.5 Ncm (Chen et al, 2006) which is the removal torque of orthodontic miniscrew that was inserted on mandible of human for 14 months, and it also is lower than that of prosthetic implant of which the removal torque is higher than 20 Ncm. However, in that experiment, 13-17 mm length miniscrew was used and it was longer than the length of miniscrew used in this study by 7 mm. Also, tested orthodontic miniscrew had been applied for 14 months., It is judged that the removal torque increased over time. And it is considered to be an increase of removal torque due to an increase of the diameter because diameter over 5 mm which is larger than the diameter of implant used in this study by 1.5 mm (Ivanoff et al, 1997). In the case of prosthetic transitional implant on which immediate loading was given, the diameter was 1.8 mm which was similar to that of orthodontic miniscrew, but it has been reported that high removal torque over 10 Ncm after 7 month maintenance period (Simon and Caputo, 2002). Therefore, it is considered that measurement of removal torque after a long-term maintenance period after insertion are necessary as well.

Anodic oxidized miniscrew showed a statistically significant increase at 3 weeks and at 12 weeks compared to machined surfaced miniscrew (p <0.05). It is thought that the increase of the surface area due to anodic oxidization surface treatment and the increase of bone bonding ability inside the bone brought the increase of removal torque. It is considered that osseointegration of anodic oxidization miniscrew is better than that of machined surface miniscrew. However, it is not absolutely superior to other types of surface treatments such as SLA, HA, plasma ion planting and Ca-P coating in point of bone bonding ability. Therefore, it is considered that more various verifications through comparison with other surface treatment methods will be necessary.

It is considered that removal of orthodontic miniscrew after orthodontic treatment is finished should be easy and also the consideration on the fracture of orthodontic miniscrew are necessary , because miniscrew is used for a shorter period than that of prosthetic implant also it should be removed after use unlike in prosthetic implant.

In addition, because the subject of the experiment was beagle, it is expected that there should be differences in bone quality, overall oral hygiene, dealing ways on operation site of the experiment subject, and it is thought that complemented studies on biomechanical stability through observations through various terms will be necessary although this experiment was done only through 12 weeks.

V. CONCLUSIONS

The aim of this study is to evaluate the biomechanical stability of anodic oxidation miniscrew compared with machined surface miniscrew. The surface roughness of miniscrews were observed using SEM. A total 48 miniscrew were placed in 6 beagle dogs. Insertion torque and removal torque were measured using torque sensor. Periotest value was recorded during experiment. The force was applied reciprocally using Ni-Ti coil spring (250-300 gm) at 3 and 12 weeks of each loading period. Beagle dogs were sacrificed, histological features were observed. The results were as follows:

1. The overall success rate was 98%. There was one machined surface miniscrew with failure.
2. Anodic oxidized miniscrews showed 12.5 Ncm which was a little higher insertion torque value compared with 12.2 Ncm in machined surface miniscrews. But, there was no significant difference ($P > 0.05$).

3. Periotest values were significantly different between anodic oxidized miniscrew groups and machined surface miniscrew groups as time passed (P <0.05). Anodic oxidized miniscrews showed lower periotest value compared with machined surface miniscrews. But, there was no significant difference (P >0.05).
4. The removal torque was significantly different between anodic oxidized miniscrews and machined surface miniscrews (P <0.05) at 3 weeks and at 12 weeks. But, no significant difference was found between inter-groups at 3 weeks and at 12 weeks (P >0.05).
5. In histological observation, anodic oxidized miniscrew group showed more mature bone adjacent to miniscrew as time passed.

These results presented that anodic oxidized miniscrews has a higher stability potential than that of machined surface miniscrews at 3 and 12 weeks. But, it is considered that further comparative study on various surface treatments on miniscrews is needed.

REFERENCES

Albrektsson T, Wennerbreg A. 2004. Oral implant surface: part I. Review focusing on topographic and chemical properties of different surfaces and in vivo responses to them. *International Journal of Prosthodontics* 17: 536-543.

Akca K, Chang TL, Tekdemir I, Fanuscu MI. 2006. Biomechanical aspects of initial intraosseous stability and implant design: a quantitative micro-morphometric analysis. *Clin Oral Implants Res* 17:465-72.

Boyan, BD, Hummert TW, Dean DD, Schwartz Z. 1996. Role of material surfaces in regulating bone and cartilage cell response. *Biomaterials* 17(2): 137-146.

Buchter A, Wiechmann D, Koerdt S, Wiesmann HP, Piffko J, and Meyer U. 2005. Load-related implant reaction of mini-implants used for orthodontic anchorage. *Clinical Oral Implants Research* 16:473-479.

Cha JY, Yoon TM, Hwang CJ. 2008. Insertion and removal torques according to orthodontic mini-screw design. *Korean J Orthod* 38: 5-12.

Chen CH, Chang CS, Hsieh CH, Tseng YC, Shen YS, Huang IY, Yang CF and Chen CM. 2006a. The use of microimplants in orthodontic anchorage. *J Oral Maxillofac Surg* 64:1209-13.

Chen Y, Shin HI, Kyung HM. 2008. Biomechamical and histological comparison of self-drilling and self-tapping orthodontic microimplants in dogs. *Am J Orthod Dentofacial Orthop* 133:44-50.

Chen YJ, Chen YH, Lin LD, Yao CC. 2006b. Removal torque of miniscrews used for orthodontic anchorage--a preliminary report. *Int J Oral Maxillofac Implants* 21:283-9.

Cheng SJ, Tseng IY, Lee JJ, Kok SH. 2004. A prospective study of the risk factors associated with failure of mini-implants used for orthodontic anchorage. *Int J Oral Maxillofac Implants* 19:100-6.

Choi JH, Lim YJ, Kim CW, Kim MJ. 2009. The effect of different screw-tighting techniques on the stress generated on an internal-connection implant superstructure. *Int J Oral Maxillofac Implants* 24(6): 1045-1053

Choi SH. 2012. Surface change of the anodic oxidized orthodontic titanium miniscrew. *Angle Orthod* 82:522-28..

Cho SA, Park KT. 2003. The removal torque of titanium screw inserted in rabbit tibia by dual acid etching. *Biomaterials* 24:4859-63.

Costa A, Rafffaini M, Melsen B. 1998. Miniscrews as orthodontic anchorage: a preliminary report. *Int J Adult Orthod Orthoganth Surg* 13:201-209.

Elias CN, Oshida Y, Lima J, Muller CA. 2008. Relationship between surface properties (roughness, wettability and morphology) of titanium and dental implant removal torque*. J Mech Behav Biomed Mater* 1: 243-242

Habig KH. 1990. Friction and wear of sliding coated with TiC, Titanium Nitride or TiB sub2. *Surface and Coatings Technology*. 133-147

Homolka P, Beer A, Birkfellner W, Nowotny R, Gahleitner A, Tschabitscher M, Bergmann H. 2002. Bone mineral dentistry measurement with dental quantative CT prior to dental implant placement in cadaver mandibles: pilot study. Radiology 224(1):247-52.

Huja SS, Litsky AS, Beck FM, Johnson KA, Larsen PE. 2005. Pull-out strength of monocortical screws placed in the maxillae and mandibles of dogs. *Am J Orthod Dentofacial Orthop* 127:307-13.

Ivanoff CJ, Sennerby L, Johansson C, Rangert B, Lekholm U. 1997. Influence of implant diameters on the integration of screw implants. *Int I oral Maxillofacial Surg* 26:141-8.

Jang SH. 2011. Biological evaluation of precipitation hardened anodic oxidation orthodontic miniscrew in the beagle dog. *Yonsei University*.

Jeon MS, Kang YG, Mo SS, Lee KH, Kook YA, Kim SH. 2008. Effects of surface treatment on the osseointegration potential of orthodontic mini-implant. *Korean J Orthod* 38: 328-36.

Joes U, Butcher A, Weismann HP, and Meyer U. 2005. Strain driven fast osseointegration of implants*. Head Face Med* 1:6.

Johansson C, Albrektsson T. 1987. Integration of screw implants in the rabbit: A 1-year follow up of removable torque of titanium implants. *Int J Oral Maxillofac Implants* :69-75

Kim KH, Ramaswany N. 2009. Electrochemical surface modification of titanium in dentistry. *Dental materials journal* 28:20-36.

Kim SH, Cho JH, Chung KR, Kook YA, Nelson G. 2008. Removal torque values of surface-treated mini-implantss after loading. *Am J Orthod Dentofacial Orthop* 134:36-43.

Klockkevold PR, Johnson P, Dadgostari S, Caputo A, Davies JE, Nishimura RD. 2001. Early endoosseous integration enhanced by dual acid etching of titanium: a torque removal study in the rabbit. *Clin Oral Implants Res* 12:350-7

Koh JW, Yang JH, Han JS, Lee JB, Kim SH. 2009. Biomechanical evaluation of dental implants with different surfaces: Removal torque and resonance frequency analysis in rabbitss. *J Adv Prosthodont* 1:107-12.

Larsson C, Thomsen P, Aronsson BO, Rodahl M, Lausmaa J, Kasemo B, Ericson LE. 1996. Bone response to surface-modified titanium implants: studies on the early tissue response to machined and electropolished implants with different oxide thickness. *Biomaterials* 17(6): 605-616

Lim HJ, Eun CS, Cho JH, Lee KH, Hwang HS. 2009. Factors associated with initial stability of miniscrews fot orthodontic treatment. *Am J Orthod Dentofacial Orthop* 136:236-42.

Lim SA, Cha JY, Hwang CJ. 2007. Comparison of insertion torque regarding changes in shape, diameter, and length of orthodontic miniscrews. *Korean J Orthod* 37: 89-97.

Lim YJ, Oshida Y, Andres CJ, Barco MT. 2001. Surface characterization of variously treated titanium materials. *Int J Oral Maxillofac Surg* 16:333-42.

Lim JW, Kim WS, Kim IK, Son CY, Byun HI. 2003. Three dimensional finite element method for stress distribution on the length and diameter of orthodontic miniscrew and cortical bone thickness. *Korean J Orthod* 33:11-20

Meredith N. 1998. Assessment of implant stability as a prognostic determinant. *Int J Prosthdont* 11:491-501

Miyawaki S, Koyama I, Inoue M, Mishima K, Sugahara T, and Takano-Yamamoto T. 2003. Factors associated with the stability of titanium screws placed in the posterior region for orthodontic anchorage. *Am J Orthod Dentofacial Orthop* 124:373-8.

Motoyoshi M, Hirabayashi M, Uemura M, and Shimizu N. 2006. Recommended placement torque when tightening an orthodontic mini-implant. *Clin Oral Implants Res* 17:109-14.

Oh NH, Kim SH, Kook YA, Lee KH, Kang YG, Mo SS. 2006. Removal torque of sandblasted large grit, acid etched treated mini-implant. *Korean J Orthod* 36: 324-30.

Okuyama K, Abe E, Suzuki T, Tamura Y, Chiba M, Sato K. 2000. Can insertional torque predict screw loodening and related failure? An in vivo study of pedicle screw fixation augumenting posterior lumbar interbody fusion. *Spine* :858-864

O'Sullivan D, Sennerby L, and Meredith N. 2000. Measurements comparing the initial stability of five designs of dental implants: a human cadaver study. *Clin Implant Dent Relat Res* 2:85-92.

Park HS. 2006a. A miniscrew-assisted transpalatal arch for use in lingual orthodontics*. J Clin Orthod* 40:12-6.

Park HS. 2006b. Histologic and biomechanical characteristics of orthodontic self-drilling and self-tapping microscrew implants. *Korea J Orthod* 36:16-29.

Park HS, Kwon TG. 2004. Sliding mechanics with microscrew implant anchorage. *Angle Orthod* 74:703-10.

Schulte W, Lukas D. 1992. The Periotest method. *Int Dent J* 42:433-40.

Simon H, Caputo AA. 2002. Removal torque of immediately loaded transitional endosseous implants in human subjects. *Int J Oral Maxillofac Implants* 17:839-845.

Sowden D, Schmitz JP. 2002. AO self-drilling and self-tapping screws in rat calvarial bone: an ultrastructural study of the implant interface. *J Oral Maxillofac Surg* 60:294-9; discussion 300.

Strnad J, Strnad Z, Šestak J, Urban K, Povýšyl C. 2007. Bioactivated titanium surface utilizable for mimetic bone implantation in dentistry-Part Ⅲ: Surface characteristics and bone implant contact formation. *J Phys Chem Solids* 68:841

Tseng YC, Hsieh CH, Chen CH, Shen YS, Huang IY, and Chen CM. 2006. The application of mini-implants for orthodontic anchorage. *Int J Oral Maxillofac Surg* 35:704-7.

Ueda M, Matsuki M, Jacobsson M, and Tjellstrom A. 1991. Relationship between insertion torque and removal torque analyzed in fresh temporal bone. *Int J Oral Maxillofac Implants* 6:442-7.

Umemori M, Suwagara J, Mitani H, Nagasaka H, Kawamura H. 1999. Skeletal anchorage system for open-bite correction. *Am J Orthod Dentofacial Orthop* 115:166-74.

Yoon BS, Choi BH, Lee YU, Kim KN, Shim HB, Park JH. 2001. A study on titanium miniscrew as orthodontic anchorage; An experimental investigation in dogs. *Korean J Orthod* 31:517-23.

Zhu X, Kim KH, Jeong Y. 2001. Anodic oxide films containing Ca and P of titanium biomaterial. *Biomaterials* 22:2199-2206.

국 문 요 약

양극산화 표면처리된 미니스크류의 생역학적 평가

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이 석 민

본 연구는 교정용 미니스크류에 양극산화 표면처리를 시행하여 생역학적인 안정성을 평가하고자 하였다. 교정용 미니스크류의 식립후 시기별 안정성과 골 결합능력을 알아보기 위해 양극산화된 미니스크류와 표면처리를 하지않은 미니스크류를 사용하여, 식립 토크 및 동요도와 제거 토크 측정을 시행하였다. 식립 전에 주사전자 현미경을 이용하여 각 군의 표면의 형태 및 거칠기를 관찰하였다. 성견 6 마리의 하악 협측골에 직경 1.45 mm, 길이 7 mm 의 self-drilling 형태의 미니스크류를 각각 24 개씩 식립하였다. 식립후 즉시 부하를

적용한 후, 성공률, 식립 토크, 동요도, 그리고 제거 토크를 측정하였다. 동물 희생 후 조직시편을 채득하여 조직학적인 변화를 비교 관찰하였다.

1. 식립된 총 48 개의 미니스크류에서 전체적인 성공률은 98% 이였다.
2. 식립 토오크는 실험군과 대조군에서 각각 12.5 Ncm 과 12.2 Ncm 로, 통계학적으로 유의한 차이는 없었다($P > 0.05$).
3. 동요도 측정에 있어서, 측정시기 간에는 통계학적인 유의차가 있었으며 ($P < 0.05$), 측정시기에 각 군간에는 통계학적으로 유의한 차이는 없었다 ($P > 0.05$).
4. 제거 토오크는 실험군과 대조군에서 3 주시 4.1 Ncm, 2.4 Ncm 와 12 주시 4.6 Ncm, 2.5 Ncm 으로 각 군간에 통계학적으로 유의한 차이가 있었다 ($P < 0.05$)
5. 조직학적인 비교에서 양극산화된 미니스크류에서 시간이 경과함에 따라 미니스크류의 표면에 성숙골이 비교적 치밀하게 형성되는 것이 관찰되었다.

본 연구에서 양극산화된 미니스크류에서 비교적 더 높은 골 결합성이 관찰되었으며, 이는 미니스크류의 식립시 생역학적인 안정성에 도움이 될 것으로 보이며, 다양한 비교 연구가 필요하리라 여겨진다.

핵심 되는 말: 양극산화 미니스크류, 동요도, 식립 토크, 제거 토크.