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치의학석사학위논문

Stability of Miniscrews Depending on
Surface Treatments
and Insertion Methods

표면처리와 식립방법에 따른
미니스크류의 안정성에 대한연구

2013 년 8 월

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Stability of Miniscrews Depending on Surface Treatments and Insertion Methods

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–Abstract–

Stability of Miniscrews Depending on Surface Treatments and Insertion Methods

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Machined surface of miniscrews for intermaxillary or orthodontic anchorage is usually stabilized only by mechanical compression and friction between cortical layer of alveolar bone and miniscrew. Rough surface of miniscrew may increase the stability of miniscrew by additional surface enlargement and osseointegration. This experimental study was aimed to evaluate the stability of miniscrews and osseous responses depending on surface treatments and insertion methods (pre-drilling and self-tapping placement).

Miniscrews (2 mm in diameter, 6 mm in length) (n=204) with three different surface treatments, were implanted in the tibiae of the adult New Zealand white rabbits (n=17, 3kg in weight). Machine surfaces (MS) (n=68), acid etched surfaces (AS) (n=68), and resorbable blast medias (RBM) (n=68) were implanted in the head (upper part) and in the body (middle part) of tibiae by two different

methods: pre-drilling and self-tapping techniques. After healing of two-, four-, and eight- week period, removal torque test was performed for all rabbits. Two rabbits were used for histological and histomorphometric analyses.

There was no fracture of miniscrew during placement and at the time of removal torque test. Nine miniscrews could not be evaluated due to the minor fracture of tibiae around inserted sites at the body part during surgery. The mean removal torque value of MS (4.41 ± 1.67 N/cm) was significantly lower than that of AS (8.34 ± 4.41 N/cm) ($p=0.000$), and of RBM (7.94 ± 2.75 N/cm) ($p=0.000$). Regarding healing time, the value of removal torque at 2-week healing (6.57 ± 2.75 N/cm) and 4-week healing (5.98 ± 2.26 N/cm) was statistically lower than that of 8-week healing (8.24 ± 5.00 N/cm) ($p=0.003$ and $p=0.000$, respectively). The body of tibia required higher torque for removing miniscrews than head of tibia at all healing times. However, there was no statistically significant difference regarding methods of placement of pre-drilling and self-tapping on removal torque. The percentage of bone-to-metal contact of MS was statistically lower than that of AS, the mean BIC ratio for MS and AS was 10.88 ± 6.10 % and 18.27 ± 7.29 % ($p=0.002$) respectively. The mean BIC ratio at 2-week healing (9.11 ± 5.98 %) was statistically lower than that at 4-week healing (14.84 ± 7.30 %) ($p=0.027$), and at 8-week healing (18.88 ± 10.11 %) ($p=0.000$). There was no difference of BIC ratio between head and body of tibia at two weeks, four weeks, and eight weeks, but the value of BIC ratio in pre-drilling showed significant lower than that of self-tapping at 4-week healing ($p=0.023$). Concerning new bone formation, there was no statistically significant difference between MS, AS, and RBM, but the BA at two weeks (1.30 ± 1.69 cm²) and at four weeks (0.95 ± 1.57 cm²) was significantly lower than that at eight weeks (5.24 ± 2.20 cm²) ($p=0.000$ and $p=0.000$, respectively). However, no statistically significant differences between head and body of tibia as well as between pre-drilling and self-tapping were observed.

The result suggested that AS and RBM surfaces showed higher removal

torque than MS due to higher ratio of bone-to-metal contact. The removal torque was higher at the body of tibia than that at the head of tibia. The self-tapping method revealed higher percentage of BIC than pre-drilling method at four weeks which suggested the higher osseointegration of self-tapping method compared to the pre-drilling method.

Keywords: surface treatment, removal torque, miniscrew, bone-to-metal contact, bone formation

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I. Introduction

Miniscrews is used for orthodontic anchorage as well as for intermaxillary fixation after orthognathic surgery, the treatment of maxillofacial trauma and fracture, and obturator retention after maxillectomy¹⁻⁷. Therefore, it has been called as “skeletal anchorage system” or “Temporary anchorage device”. For those purposes, it has many advantages such as easy placement, no delay in loading, low cost, good patient compliance and simple removal procedure due to small size^{1,2}. The conventional miniscrews for SAS is composed of titanium material with machined surface and self-tapping insertion power, and its stability is maintained mainly by mechanical interlocking between miniscrew and surrounding bone. Therefore, its application is limited in long term use and in poor bone quality because of limited osseointegration of miniscrews.

The stability of miniscrew has been attributed to many factors.

Biocompatibility and host reactivity including quality and quantity of surrounding bone usually influence the success rate of miniscrew⁸. Surface characteristics of miniscrew such as surface topography, surface design and chemistry, and surface charge have been found to enhance biomimetic response⁹. The general concept of dental implant suggests that surface roughness increases the potential for biomechanical interlocking of bone into implant surface. Some studies have demonstrated that increased surface topography enhanced osseointegration of bone to implant contact^{10,11}. In animal studies, the bone to implant contact and removal torque were found to be higher in roughed implant than in machined implant^{10,12,13,14}. Miniscrews are generally untreated smooth surface made by pure titanium or titanium alloy. The studies of surface treated miniscrew revealed that sandblasting and acid etching (SLA) provided higher osseointegration than machined miniscrews^{15,16}. Initially, the concept of miniscrew was skeletal anchorage with short duration and easy removal¹⁷; therefore, it has been regarded that osseointegration is not desirable¹⁸. Recently skeletal anchorage has been more frequently used for long term, and miniscrew which is able to be osseointegrated has been requested, especially in patients with thin cortical layer or in young patients with soft bone quality.

The primary stability of miniscrew was influenced by many factors. According to literature, cortical bone with higher density achieved greater primary stability of miniscrew^{19,20}. Cancellous bone had little effect on primary stability, however, it may influence the secondary stability in long term²⁰. Insertion method was found to be one of the factors influencing the primary stability of miniscrews²¹. Pre-drilling method is generally accepted for the insertion of miniscrew in cranio-maxillofacial surgery and in orthodontics. Pre-drilling reduces the risk of miniscrew fracture, osseous compression with microdamage or bone necrosis around miniscrew, therefore, it can be used in the region with high cortical thickness²². However, this procedure needs pilot drilling before miniscrew insertion which can damage to tooth roots, drill-bit breakage,

over-drilling, and thermal necrosis of the bone^{23,24}. Self-tapping reduces the risk of root damage because the pilot drilling is not required²⁵. It is simpler and quicker, little bone debris and less bone overheated, but it should be used in thin cortical bone region like at midface, otherwise it increases the risk of miniscrew fracture²⁵⁻²⁷.

Even though there were some studies about the surface treatment of miniscrew or the effect of pre-drilling and self-tapping, those studies were performed only for the simple comparison of removal torque or histomorphometric value between machine surface (MS) and resorbable blast medias (RBM), or between MS with SLA, or between MS with acid etched surface (AS), or only simple comparison between pre-drilling and self-tapping. And a comparison between MS and RBM and AS depending on different insertion methods has not been yet reported, and there were no studies about the effect of inter-distance of miniscrew on its stability. Therefore, the aim of this study was to conduct the direct comparative analysis of stability between MS and AS and RBM in term of removal torque, new bone formation around miniscrew depending on the thickness of cortical bone and the inter-distance of miniscrew at head and body of tibia, and the insertion method with pre-drilling and self-tapping.

II. Material and Methods

1. Miniscrews

Self-tapping miniscrews (2 mm in diameter, 6 mm in length) (n=204) with three different surface treatments, namely MS (n=68), AS (n=68), and RBM (n=68), were fabricated by (JEIL MEDICAL CORPORATION, Seoul, Korea) (Figure 1). AS was obtained by etching with hydrofluoric acid (HF) and RBM was achieved by blasting with calcium phosphate (Ca-P) and then incubating with nitric oxide (HNO₃).

2. Animal experiment

Seventeen adult New Zealand white rabbits (3kg) were used in the study. The animals were anesthetized with a combination of Zoletil (Virbac Korea, Seoul, Korea) and Rampun (Bayer Korea, Seoul, Korea) intramuscularly and intravenously (0.35 ml: 0.15 ml). Before surgery, the skin of the tibiae was shaved and decontaminated with Povidone iodine solution (Green Pharm, Seoul, Korea). At the insertion sites, 1.8 ml of lidocaine HCL with adrenaline (1:100,000) (Houns Co., Ltd, Seoul, Korea) was injected. Immediately after surgery, each animal was intramuscularly injected with cefazolin (Chongkeundang Pharma Co, Seoul, Korea) at a dose of 2.5 ml. All animals were given antibiotics only one time immediately after surgery.

2-, 4-, 8- weeks after surgery, animals were sacrificed with an intravenous injection of KLC-40 (JEIL PHAMARCEUTICAL Co.Ltd, Dague, Korea) at a dose of 6 ml.

2.1 Surgery

The tibia metaphysis was surgically exposed via the skin incision, and the muscles were dissected to allow elevation of the periosteum. Twelve miniscrews were placed in each rabbits (six on each side of tibia). Miniscrews with three

kinds of surface were placed at the upper part (head) and the middle part (body) of each side of tibia for all animals with two different insertion methods, namely pre-drilling at the right tibia and self-tapping at the left tibia. Each miniscrew was inserted around 3 mm from one another at tibia head and 10 mm from each other at tibia body. All miniscrews were inserted in the same position for all animals (Figure 2A).

For pre-drilling technique, six pilot holes were drilled with a 2-mm diameter drill bit under copious irrigation with normal saline at the head and the body of tibia. Miniscrews with three different surfaces were placed into the pre-drilled holes with a manual screwdriver (Figure 2B-E).

For self-tapping technique, miniscrews were inserted directly by manual screwdriver under irrigation with normal saline at both head and body of tibia (Figure 2F-G).

2.2 Removal torque

The torque necessary to loosen the miniscrew in both head and body of tibia was evaluated by an electric torque measuring machine (AIKOM ENGINEERING, Osaka, Japan). The measurement of removal torque was conducted for all miniscrews.

3. Histomorphometric evaluation

For histomorphometry, animals were sacrificed after two- (n=2), four- (n=2), and eight weeks of healing (n=2), respectively. After removal of miniscrew, samples at the site of miniscrew placement were resected en bloc separately at the head and body part and immediately decalcified in EDTA solution (7%, pH = 7.0) for 7 days. After fixing in 10% formalin for 4 weeks, samples were dehydrated in 70% ethanol and embedded in paraffin. For histochemical analysis, they were stained with masson trichrome for the detection of cell and bone structures

The histological examinations were evaluated for bone-to-metal contact (BIC) in ratio and for new bone formation (BA). BIC was determined by the direct bone contact with miniscrew surface. The sum of linear bone contact with miniscrew surface was calculated and expressed as percentage over the total miniscrew length. The area of new bone formation between the miniscrew threads was measured for BA. The digital images from stained sections were taken by a transmission and polarized light Olympus BX51 Microscope (Olympus, Tokyo, Japan), equipped with a digital camera (U-CMAD3, Olympus, Tokyo, Japan) and analyzed using a computerized image analysis system, SPOT Advanced version 4.6 (Diagnostic Instrument) at 1.25 x magnification.

4. Statistical analysis

The statistical analyses were performed using SPSS program version 20 (SPSS Inc., Chicago, IL, USA). The normal distribution of the measurements was verified by One-Sample Kolmogorov-Smirnov normality test. Descriptive statistics and multiple comparisons between groups were performed with one-way analysis of variance (ANOVA) and the post-hoc Tukey test to detect any differences between different miniscrew surfaces depending on healing time. The two-way analysis of variance and the post-hoc Tukey test was used to analyzed the differences between different miniscrew surfaces depending on different locations of placement and the differences between different insertion methods. T-test was performed to find the difference between each method of placement and between each location as well as the difference of cortical bone thickness between head and body of tibia. P values < 0.05 were considered significant.

III. Results

There was no fracture of miniscrews during placement and at the time of removal torque test. Nine miniscrews could not be evaluated because of loosening of screws from over-compression of surrounding bone at the insertion site by screws.

1. Removal Torque Measurement

1.1 Comparison depending on surface treatments

The value of removal torque depending on the surfaces of miniscrew was shown in table 1. The removal torque increased significantly according to prolonged healing time. The removal torque at 2-week (6.57 ± 2.75 N/cm) and 4-week (5.98 ± 2.26 N/cm) was lower than that of 8-week (8.24 ± 5.00 N/cm) with statistically significant difference ($p=0.003$ and $p=0.000$, respectively) (Figure 3A). There was statistically significant increase in removal torque at 2-week for AS (7.35 ± 2.84 N/cm) and RBM (7.75 ± 2.65 N/cm) than that for MS (4.61 ± 1.57 N/cm) ($p=0.001$ and $p=0.000$, respectively) (Figure 3B). At 4-week, the removal torque for AS (5.98 ± 1.57 N/cm) and RBM (7.55 ± 2.26 N/cm) was statistically significant higher than that for MS (4.51 ± 1.86 N/cm) ($p=0.050$ and $p=0.000$, respectively); the removal torque for RBM was significantly higher than that for AS ($p=0.021$) (Figure 3B). The removal torque at 8-week for AS (12.06 ± 5.59 N/cm) and RBM (8.53 ± 3.24 N/cm) was significantly higher than that for MS (4.02 ± 1.67 N/cm) ($p=0.000$ and $p=0.001$, respectively) (Figure 3B).

1.2 Comparison depending on locations

The thickness of cortical bone was 2.25 ± 0.59 mm in the head and 2.49 ± 0.51 mm in the body region. There was no statistically significant difference of the thickness of cortical bone between head and body of tibia ($p= 0.76$) (Table 2).

Table 3 presented the result of removal torque depending on the locations of placement at 2-week, 4-week, and 8-week healing. There was a statistically significant increase in removal torque at tibia body than that at tibia head at 2-week (Figure 4A), at 4-week (Figure 4B), and at 8-week (Figure 4C). At tibia head, the result of 2-week revealed that there was statistically significant increase of removal torque for AS (6.84 ± 2.25 N/cm) and RBM (6.74 ± 2.02 N/cm) than that for MS (4.09 ± 1.14 N/cm) ($p=0.003$ and $p=0.000$, respectively). At tibia body, the removal torque for RBM (8.75 ± 2.96 N/cm) was significantly higher than that for MS (5.14 ± 1.74 N/cm) ($p=0.013$). There was no statistically significant different in removal torque for MS, AS, and RBM between tibia head and tibia body (Figure 4A).

At four-week healing, the removal torque at tibia head was statistically significant higher for AS (5.52 ± 1.12 N/cm) and RBM (6.15 ± 1.35 N/cm) than that for MS (3.90 ± 1.42 N/cm) ($p=0.012$ and $p=0.000$, respectively). At tibia body, the removal torque for RBM (9.25 ± 1.99 N/cm) was significantly higher than that for MS (5.33 ± 2.13 N/cm) and AS (6.48 ± 1.99 N/cm) ($p=0.001$ and $p=0.014$, respectively). The removal torque of RBM at tibia body (9.25 ± 1.99 N/cm) was statistically significant higher than that at tibia head (6.15 ± 1.35 N/cm) ($p=0.001$). There was no statistically significant different in removal torque for MS and AS between tibia head and tibia body (Figure 4B).

At eight-week healing, removal torque at tibia head was statistically significant higher for AS (9.95 ± 5.86 N/cm) and RBM (7.09 ± 2.94 N/cm) than that for MS (3.18 ± 0.71 N/cm) ($p=0.000$ and $p=0.044$, respectively). At tibia body, the removal torque for AS (12.09 ± 5.34 N/cm) and RBM (9.84 ± 2.61 N/cm) was significantly higher than that for MS (4.85 ± 1.78 N/cm) ($p=0.000$ and $p=0.005$, respectively). The removal torque of MS at tibia body (4.85 ± 1.78 N/cm) was statistically significant higher than that at tibia head (3.18 ± 0.71 N/cm) ($p=0.018$). There was no statistically significant different in removal torque for AS and RBM between tibia head and tibia body (Figure 4C).

1.1 Comparison depending on insertion methods

The result of removal torque depending on methods of placement was presented in table 4. There was no statistically significant difference of removal torques in all healing periods between pre-drilling and self-tapping technique (Figure 5A-C). Regarding pre-drilling at 2-week healing, removal torque was statistically significant higher for AS (7.38 ± 2.37 N/cm) and RBM (7.12 ± 2.05 N/cm) than that for MS (4.81 ± 1.52 N/cm) ($p=0.002$ and $p=0.006$, respectively). Regarding self-tapping, the removal torque for AS (7.39 ± 3.32 N/cm) and RBM (8.23 ± 3.12 N/cm) was significantly higher than that for MS (4.39 ± 1.56 N/cm) ($p=0.029$ and $p=0.004$, respectively). There was no statistically significant different in removal torque for MS, AS, and RBM between pre-drilling and self-tapping (Figure 5A).

For pre-drilling at 4-week, removal torque was statistically significant higher for AS (6.03 ± 1.47 N/cm) and RBM (6.81 ± 2.03 N/cm) than that for MS (4.19 ± 0.97 N/cm) ($p=0.035$ and $p=0.001$, respectively). For self-tapping, the removal torque for AS (5.88 ± 1.81 N/cm) and RBM (8.31 ± 2.33 N/cm) was significantly higher than that for MS (4.91 ± 2.49 N/cm) ($p=0.046$ and $p=0.000$, respectively). There was no statistically significant different in removal torque for MS, AS, and RBM between pre-drilling and self-tapping (Figure 5B).

Concerning pre-drilling at 8-week, removal torque was statistically significant higher for AS (10.86 ± 5.83 N/cm) and RBM (7.61 ± 1.92 N/cm) than that for MS (3.58 ± 1.11 N/cm) ($p=0.000$ and $p=0.047$, respectively). Concerning self-tapping, the removal torque for AS (13.29 ± 5.28 N/cm) and RBM (9.44 ± 4.06 N/cm) was significantly higher than that for MS (4.46 ± 2.04 N/cm) ($p=0.000$ and $p=0.026$, respectively). There was no statistically significant different in removal torque for MS, AS, and RBM between pre-drilling and self-tapping (Figure 5C).

2. Histomorphometric evaluation

1.1 Comparison depending on surface treatments

The value of BIC depending on the surfaces of miniscrew was shown in table 5. The BIC ratio at 2-week healing ($9.11 \pm 5.98 \%$) was statistically lower than that at 4-week healing ($14.84 \pm 7.30 \%$) ($p=0.027$), and at 8-week healing ($18.88 \pm 10.11 \%$) ($p=0.000$); the BIC ratio for MS ($10.88 \pm 6.10 \%$) was significantly lower than that for AS ($18.27 \pm 7.29 \%$) ($p=0.002$). There was statistically significant increase in BIC at 2-week for AS ($13.47 \pm 4.70 \%$) and RBM ($10.98 \pm 6.04 \%$) than that for MS ($3.98 \pm 2.19 \%$) ($p=0.003$ and $p=0.017$, respectively). At 4-week, there was no statistically significant difference between MS, AS, RBM regarding BIC ratio. The BIC at 8-week for AS ($26.27 \pm 11.08 \%$) was significantly higher than that for RBM ($14.50 \pm 9.21 \%$) ($p=0.040$) (Figure 3C).

The value of BA regarding surfaces of miniscrew was presented in table 6. There was no statistically significant difference regarding types of miniscrew at 2-week, 4-week, and 8-week. The Tukey test showed that the BA at 2-week healing ($1.30 \pm 1.69 \text{ cm}^2$) was statistically lower than that at 8-week healing ($5.24 \pm 2.20 \text{ cm}^2$) ($p=0.000$), and BA at 4-week healing ($0.95 \pm 1.57 \text{ cm}^2$) was statistically lower than that at 8-week healing ($p=0.000$) (Figure 3D).

2.2 Comparison depending on locations

Table 7 demonstrated the value of BIC regarding locations of placement at 2-week, 4-week, and 8-week. There was no statistically significant difference of BIC between head and body of tibia at all healing times (Figure 6A-C). For 2-week healing, there was no statistically significant difference in BIC for MS, AS, and RBM between head and body of tibia. Regarding tibia head, the difference of BIC between MS, AS, and RBM did not reach statistically significant. Regarding tibia body, BIC for AS ($14.77 \pm 3.10 \%$) and RBM ($14.15 \pm 6.00 \%$) was significantly higher than that for MS ($4.29 \pm 1.96 \%$) ($p=0.013$ and $p=0.019$, respectively) (Figure 6A). At 4-week, there was no statistically

significant difference of BIC ratio between types of miniscrew in tibia head and in tibia body, and between tibia head and tibia body (Figure 6B).

At 8-week, there was no statistically significant different in BIC for MS, AS, and RBM at head and at body of tibia. The difference of BIC between MS, AS, and RBM between head and body of tibia did not reach statistically significant (Figure 6C).

Table 8 presented the result of BA depending locations of placement. There was no statistically significant between head and body of tibia, and the result did not show a statistically significant difference of BA regarding types of miniscrew at 2-week (Figure 6D), 4-week (Figure 6E), and 8-week healing (Figure 6F). There was no statistically significant different in BA for MS, AS, and RBM at head and at body of tibia. The difference of BIC between MS, AS, and RBM between head and body of tibia did not reach statistically significant at 2-week (Figure 6D), 4-week (Figure 6E), and 8-week healing (Figure 6F).

2.1 Comparison depending on insertion methods

The result of BIC regarding methods of placement was shown in table 9. There was no statistically significant difference of BIC between pre-drilling and self-tapping technique at 2-week (Figure 7A) and 8-week healing (Figure 7C), but BIC was lower in pre-drilling than that in self-tapping methods at 4-week healing ($p=0.023$) (Figure 7B). Regarding pre-drilling at 2-week, BIC for AS ($12.10 \pm 5.07 \%$) and RBM ($13.85 \pm 4.05 \%$) was significantly higher than that for MS ($5.40 \pm 2.29 \%$) ($p=0.015$ and $p=0.029$, respectively). Regarding tibia body, BIC for AS ($16.21 \pm 3.28 \%$) and RBM ($8.10 \pm 6.83 \%$) was significantly higher than that for MS ($2.57 \pm 0.82 \%$) ($p=0.003$ and $p=0.020$, respectively). There was no statistically significant different of BIC for MS, AS, and RBM between head and body of tibia (Figure 7A).

At 4-week, there was no statistically significant difference for types of

miniscrew at tibia head and tibia body, and between tibia head and tibia body (Figure 7B). At 8-week, the difference for types of miniscrew at tibia head and tibia body, and between tibia head and tibia body did not reach statistically significant (Figure 7C).

Table 10 showed the result of BA regarding methods of placement. The result did not show any differences of BA between pre-drilling and self-tapping at 2-week (Figure 7D), 4-week (Figure 7E), and 8-week (Figure 7F). The difference of BA between MS, AS, and RBM in pre-drilling and in self-tapping did not reach statistically significant at all healing times. There was no statistically significant different of BA for MS, AS, and RBM between pre-drilling and self-tapping (Figure 7D, 7E, 7F).

IV. Discussion

Miniscrew has been used as skeletal anchorage in orthodontic or temporary intermaxillary fixation in oral and maxillofacial surgery. However, long term application of miniscrew is limited due to its weak osseointegration. It is well known that surface modification can enhance osseointegration and improve stability. For the evaluation of osseous response of titanium implant in animal experiment, the measurement of removal torque, the new bone formation using histomorphometrical analysis and micro-CT have been used as standard tools. The removal torque has been used as the adequate biomechanical parameter for endosseous implant integration²⁸. Micro-CT histomorphometric analysis provides higher level of understanding in the healing process of surrounding bone, however, metallic artifact around implant or miniscrew limits the measurement of BIC correctly²⁹. Song et al²⁹ found that the BIC value from micro-CT decreased when the pixel size of dilation (PSD) increased. Therefore, we used removal torque and histomorphometric analysis in the present study. In this study, the removal torque and the histomorphometric values were increased with prolonged healing time. The removal torque, BIC, and the amount of new bone formation were lower at 2-week healing than at those at 4-week healing. At 8-week healing, the value of removal torque and the histomorphometric value continued to increase significantly.

According to the long term use of miniscrews in orthodontic treatment, oral and maxillofacial surgery, surface modifications for the increase in osseointegration has been tried. The increased surface roughness enhanced the potential for biomechanical interlocking of the bone into implant surface which in turn improved the stability. Klokkevold et al.¹³ showed enhanced bony anchorage to dual acid etched implants compared to machined implants as well as enhanced early endosseous integration compared to more complex topography of titanium plasma spray. Some investigators reported that etched implants showed a statistically higher removal torque and BIC compared with machined

implants^{30, 31}. Kim et al.³² demonstrated that RBM had higher roughness than machined surface. Kim et al.¹⁴ reported higher removal torque and histomorphometric analysis of RBM than machined pin implant. The result of our study revealed that the removal torque of AS and RBM was statistically significant higher than that of MS at 2-week, 4-week, and 8-week healing. Regarding histomorphometric finding, BIC was statistically higher for AS and RBM than that for MS. Concerning the amount of new bone formation, there was no statistically significant differences among MS, AS, and RBM, however, the BA for AS and RBM was higher than that for MS. Le Guehennec et al.³³ reported that the blasting material used for developing grit blasted implants often remains embedded in the implant material, even after the ultrasonic cleaning of the implants these alumina particles were released into the surrounding bone and interfered with osseointegration. Klokkevold et al.¹² mentioned that acid etching appeared greatly enhanced osseointegration without adding particulate matter (e.g. titanium plasma spray or hydroxyapatite) or embedding surface contaminations (e.g. grit particles). At 8-week, the result of our study showed that BIC was statistically higher for AS than that for RBM.

Histomorphometric analysis of miniscrew revealed only partial peri-implant new bone formation which was a desirable characteristic of miniscrew used as temporary anchorage. Vande Vannet et al.¹⁸ suggested that partial osseointegration of miniscrew was a preferable characteristic for temporary anchorage. In our study, partial contact between the bone and miniscrew surface was observed for all miniscrew surfaces (Figure 8).

Nanda and Uribe³⁴ explained that the regional acceleratory phenomenon manifests as intense bone remodeling foci within 1 mm of the miniscrew-bone interface. The prevalence of bone remodeling foci progressively decreases as the distance from the miniscrew surface increases. If bone remodeling foci are intensive and broad, tissue compliance cannot be maintained, and propagation of the microdamage might continue. As a result, stability of the miniscrew can be

decreased. In our study, we placed miniscrews intimately at the head then at the body of tibia. The result showed that miniscrews inserted at body of tibia provided more stability with significant higher removal torque than those at head of tibia. Histomorphometric evaluation also showed higher BIC and BA at tibia body than those at tibia head even though there was no significant difference between head and body of tibia (Figure 10).

Motoyoshi et al.⁸ evaluated the effect of cortical bone thickness on the stability of orthodontic mini-implants and on the stress distribution in the surrounding bone. Their result showed that the success rate of the mini-implant was significantly greater at sites with cortical bone thickness more than 1 mm. Wei et al.³⁵ reported that miniscrew inserted into thick cortical bone thickness sites provided better stability than those inserted into thin cortical bone sites. The result of our study showed that the stability of miniscrew was higher at tibia body than that at tibia head. The cortical bone thickness at tibia head was 2.25 ± 0.59 mm and at tibia body was 2.49 ± 0.51 mm; however, there was no statistically significant difference between head and body of tibia. The possible reasons may be because of the distance between each miniscrew was so narrow in the head than in the body of tibia which might affect the bone healing surrounding miniscrews.

Kim et al.²¹ explained that damage caused by pre-drilling prevented bony adaptation around miniscrew. Previous investigators suggested that when the miniscrew was inserted by self-tapping, bone debris was deposited on the bone surface around the screw threads which kept initial stability and resisted micromotion as well as increased the surface contact of bone to metal²⁶. Susuki and Susuki.³⁶ found that the removal torque was significantly higher for self-tapping than that for pre-drilling. Kim et al.²¹ demonstrated that BIC and BA were lower for pre-drilling than that for self-tapping. After 4 weeks, the result of present study revealed higher stability of self-tapping than pre-drilling; the percentage of BIC was statistically higher for self-tapping than that for

Pre-drilling. Even though the result of removal torque and BA did not show statistically significant, the removal torque and BA were higher for self-tapping than those for pre-drilling (Figure 9).

V. Conclusion

This experimental study was performed to assess the stability and osseous responses of three different types of miniscrew including machine surface, acid etched surface, and RBM surface depending on the thickness of cortical bone and the inter-distance of miniscrew at head and body of tibia and between pre-drilling and self-tapping. We analyzed the removal torque as well as histomorphometric evaluation of each parameter at 2-week, 4-week, and 8-week healing. The result revealed that the value of removal torque and the BIC ratio and BA were statistically significant increase according to healing time.

1. At 2-week, 4-week, and 8-week, the removal torque was statistically significant increase for AS and RBM and was higher at tibia body while each miniscrew was inserted in an appropriate distance from one another, but there was no difference between pre-drilling and self-tapping. For BA, however, there were no statistically different between MS, AS, and RBM; between head and body of tibia; and between pre-drilling and self-tapping.
2. At 2-week, the BIC for AS and RBM was significantly higher but there was no difference between head and body of tibia as well as between pre-drilling and self-tapping.
3. At 4-week, there was no difference between MS, AS, and RBM and between head and body of tibia for BIC; however, self-tapping showed significantly higher of BIC than pre-drilling.
4. At 8-week, although there was no statistically difference between head and body of tibia and between pre-drilling and self-tapping regarding BIC, BIC for AS showed significant higher than that for RBM.
5. The cortical thickness was higher in body than in head of tibia, but this difference did not reach statistically significant.

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Tables

Table 1. Removal torque (N/cm) of miniscrews depending on surface treatments

Healing time*	Surface treatments*							
	MS (n=65)		AS (n=65)		RBM (n=65)		Total (n=195)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
2 wks (n=69)†	4.61	1.57	7.35	2.84	7.75	2.65	6.57	2.75
4 wks (n=66)††	4.51	1.86	5.98	1.57	7.55	2.26	5.98	2.26
8 wks (n=60)†††	4.02	1.67	12.06	5.59	8.53	3.24	8.24	5.00
Total (n=195)	4.41	1.67	8.34	4.41	7.94	2.75		

* 2 wks < 8 wks (p=0.003), 4 wks < 8 wks (p=0.000); MS < AS (p=0.000), MS < RBM (p= 0.000)

† MS < AS (p=0.001), MS < RBM (p= 0.000)

†† MS < AS (p=0.050), MS < RBM (p= 0.000), AS < RBM (p=0.021)

††† MS < AS (p=0.000), MS < RBM (p= 0.001)

Statistical significance by Tukey HSD test (p < 0.05).

Table 2. Comparison of cortical bone thickness between head and body of tibia

Cortical thickness					
(n= 68)	Head (n=34)		Body (n=34)		
(mm)	Mean	SD	Mean	SD	P*
	2.25	0.59	2.49	0.51	NS

NS: No statistical significance, * by student t-test (p < 0.05).

Table 3. Removal torque (N/cm) of miniscrews depending on locations

(N/cm)	Tibia head**						Tibia body***					
	MS		AS		RBM		MS		AS		RBM	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
2 wks*	4.09	1.14	6.84	2.25	6.74	2.02	5.14	1.74	7.98	3.38	8.75	2.96
4 wks†	3.90	1.42	5.52	1.12	6.15	1.35	5.33	2.13	6.48	1.99	9.25	1.99
8 wks††	3.18	0.71	9.95	5.86	7.09	2.94	4.85	1.78	12.09	5.34	9.84	2.61

* Tibia head < Tibia body (p=0.034)

† Tibia head < Tibia body (p=0.001)

†† Tibia head < Tibia body (p=0.024)

** 2 wks: MS < AS (p= 0.003), MS < RBM (p= 0.004); 4 wks: MS < AS (p= 0.012), MS < RBM (p= 0.000); 8 wks: MS < AS (p= 0.000), MS < RBM (p= 0.044)

*** 2 wks: MS < RBM (p= 0.013); 4 wks: MS < RBM (p= 0.001), AS < RBM (p= 0.014); 8 wks: MS < AS (p= 0.000), MS < RBM (p= 0.005)

Statistical significance by Tukey HSD test for surface treatments and by t-test for locations (p < 0.05).

Table 4. Removal torque (N/cm) of miniscrews depending on insertion methods

(N/cm)	Pre-drilling*						Self-tapping**					
	MS		AS		RBM		MS		AS		RBM	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
2 wks	4.81	1.52	7.38	2.37	7.12	2.05	4.39	1.56	7.39	3.32	8.23	3.12
4 wks	4.19	0.97	6.03	1.47	6.81	2.03	4.91	2.49	5.88	1.81	8.31	2.33
8 wks	3.58	1.11	10.86	5.83	7.61	1.92	4.46	2.04	13.29	5.28	9.44	4.06

* 2 wks: MS < AS (p= 0.002), MS < RBM (p= 0.006); 4 wks: MS < AS (p= 0.035),

MS < RBM (p= 0.001); 8 wks: MS < AS (p= 0.000), MS < RBM (p= 0.047)

** 2 wks: MS < AS (p= 0.029), MS < RBM (p= 0.004); 4 wks: MS < AS (p= 0.046),

MS < RBM (p= 0.000); 8 wks: MS < AS (p= 0.000), MS < RBM (p= 0.026)

There was no statistically significant difference between pre-drilling and self-tapping

Statistical significance by Tukey HSD test for surface treatments and by t-test for insertion methods (p < 0.05).

Table 5. BIC (%) of miniscrews depending on surface treatments

Healing time*	Surface treatments*							
	MS (n=24)		AS (n=22)		RBM (n=24)		Total (n=70)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
2 wks (n=22)†	3.98	2.19	13.47	4.70	10.98	6.04	9.11	5.98
4 wks (n=24)	12.78	10.30	15.07	6.10	16.67	4.78	14.84	7.30
8 wks (n=24)‡	15.86	5.80	26.27	11.08	14.50	9.21	18.88	10.11
Total (n=70)	10.88	6.10	18.27	7.29	14.05	6.68		

* 2 wks < 4 wks (p=0.027), 2 wks < 8 wks (p=0.000); MS < AS (p=0.002)

† MS < AS (p=0.003), MS < RBM (p=0.017)

‡ AS > RBM (p=0.040)

Statistical significance by Tukey HSD test (p < 0.05).

Table 6. BA (cm²) of miniscrews depending on surface treatments

Healing time*	Surface treatments							
	MS (n=24)		AS (n=22)		RBM (n=24)		Total (n=70)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
2 wks (n=22)	0.86	0.74	1.14	1.16	1.86	2.55	1.30	1.69
4 wks (n=24)	0.49	0.41	0.52	0.45	1.83	2.53	0.95	1.57
8 wks (n=24)	4.46	2.08	5.75	2.20	5.51	2.39	5.24	2.20
Total (n=70)	1.94	2.21	2.59	2.84	3.07	2.96		

* 2 wks < 8 wks (p=0.000), 4 wks < 8 wks (p=0.000)

Statistical significance is determined by Tukey HSD test (p < 0.05).

Table 7. BIC (%) of miniscrews depending on locations

(%)	Tibia head						Tibia body*					
	MS		AS		RBM		MS		AS		RBM	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
2 wks	3.67	2.67	10.87	7.84	7.81	4.71	4.29	1.96	14.77	3.10	14.15	6.00
4 wks	11.28	9.82	13.47	5.17	17.05	3.91	14.28	12.04	16.66	7.30	16.30	6.14
8 wks	18.24	6.21	26.62	14.24	10.98	4.43	13.49	5.00	25.93	9.13	12.33	12.84

* MS < AS (p= 0.013), MS < RBM (p= 0.019)

There was no statistically significant difference of BIC between head and body of tibia

Statistical significance by Tukey HSD test for surface treatments and by t-test for locations

(p < 0.05).

Table 8. BA (cm²) of miniscrews depending on locations

(cm ²)	Tibia head						Tibia body					
	MS		AS		RBM		MS		AS		RBM	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
2 wks	0.77	0.90	1.90	1.73	1.53	2.71	0.94	0.65	0.76	0.82	2.19	2.74
4 wks	0.41	0.15	0.59	0.62	0.82	0.49	0.58	0.60	0.45	0.28	2.85	3.46
8 wks	3.64	2.31	4.59	2.77	5.78	1.03	5.28	1.72	6.91	0.27	4.95	3.08

No statistical significance

Statistical significance by Tukey HSD test for surface treatments and by t-test for locations

(p < 0.05).

Table 9. BIC (%) of miniscrews depending on insertion methods

(%)	Pre-drilling**						Self-tapping***					
	MS		AS		RBM		MS		AS		RBM	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
2 wks	5.40	2.29	12.10	5.07	13.85	4.05	2.57	0.82	16.21	3.28	8.10	6.83
4 wks†	8.93	10.25	11.38	4.55	14.29	5.99	16.63	10.13	18.75	5.47	19.06	1.51
8 wks	18.14	5.68	26.68	14.18	11.87	3.72	13.59	5.70	25.86	9.22	11.92	12.83

† pre-drilling < self-tapping (p= 0.023)

** 2wks: MS < AS (p= 0.015), MS < RBM (p= 0.029)

*** 2wks: MS < AS (p= 0.003), MS < RBM (p= 0.020)

Statistical significance by Tukey HSD test for surface treatments and by t-test for insertion methods (p < 0.05).

Table 10. BA (cm²) of miniscrews depending on insertion methods

(cm ²)	Pre-drilling						Self-tapping					
	MS		AS		RBM		MS		AS		RBM	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
2 wks	0.44	0.36	0.34	0.28	2.28	3.70	0.54	0.52	0.70	0.56	1.39	0.84
4 wks	4.53	0.86	6.55	0.45	6.49	0.64	4.38	3.06	4.96	3.07	4.65	2.62
8 wks	0.37	0.11	1.11	0.59	0.78	0.20	0.46	0.21	1.36	0.54	0.96	0.41

No statistical significance

Statistical significance by Tukey HSD test for miniscrew surfaces and by t-test for placement methods (p < 0.05).

Figures

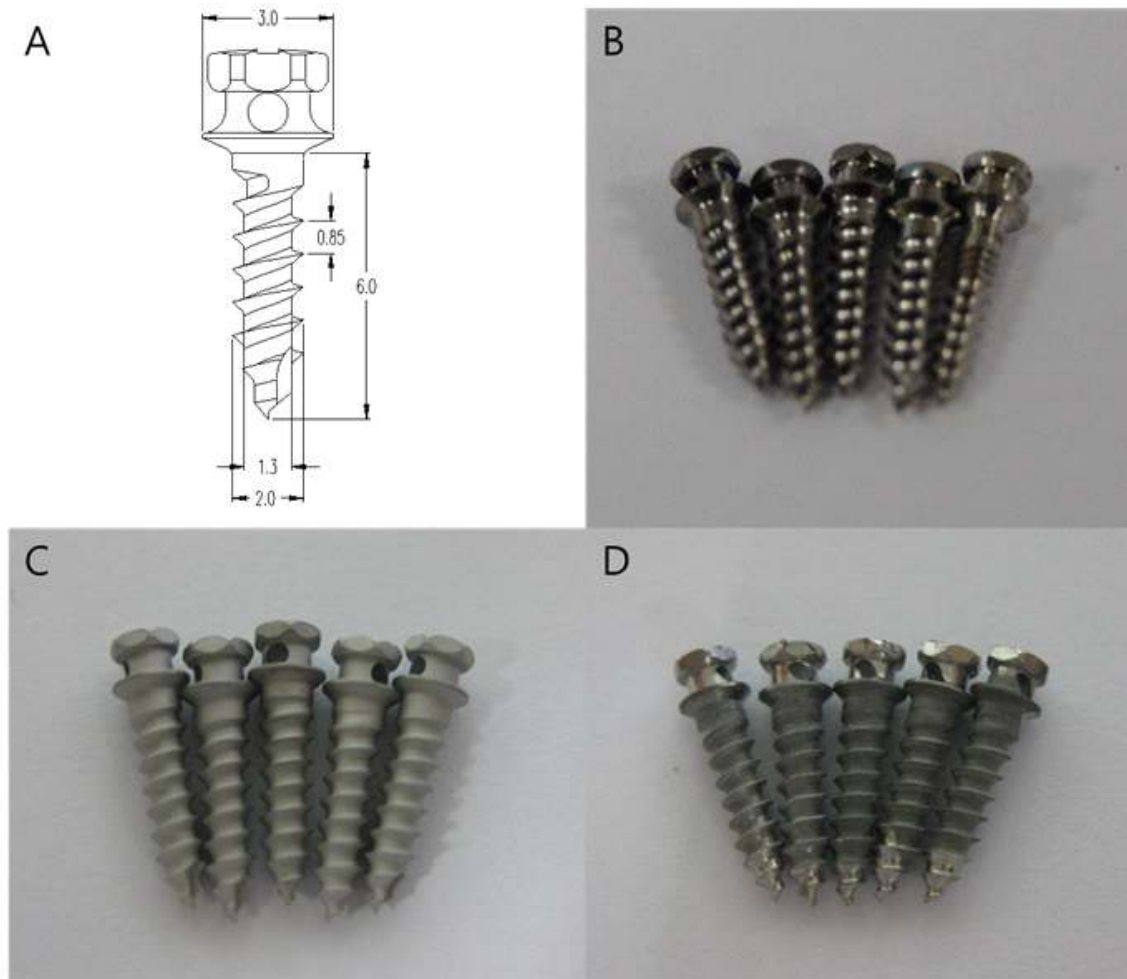


Figure 1. Miniscrew. implants. A: basic design of miniscrew, B: MS, C: AS, D: RBM.

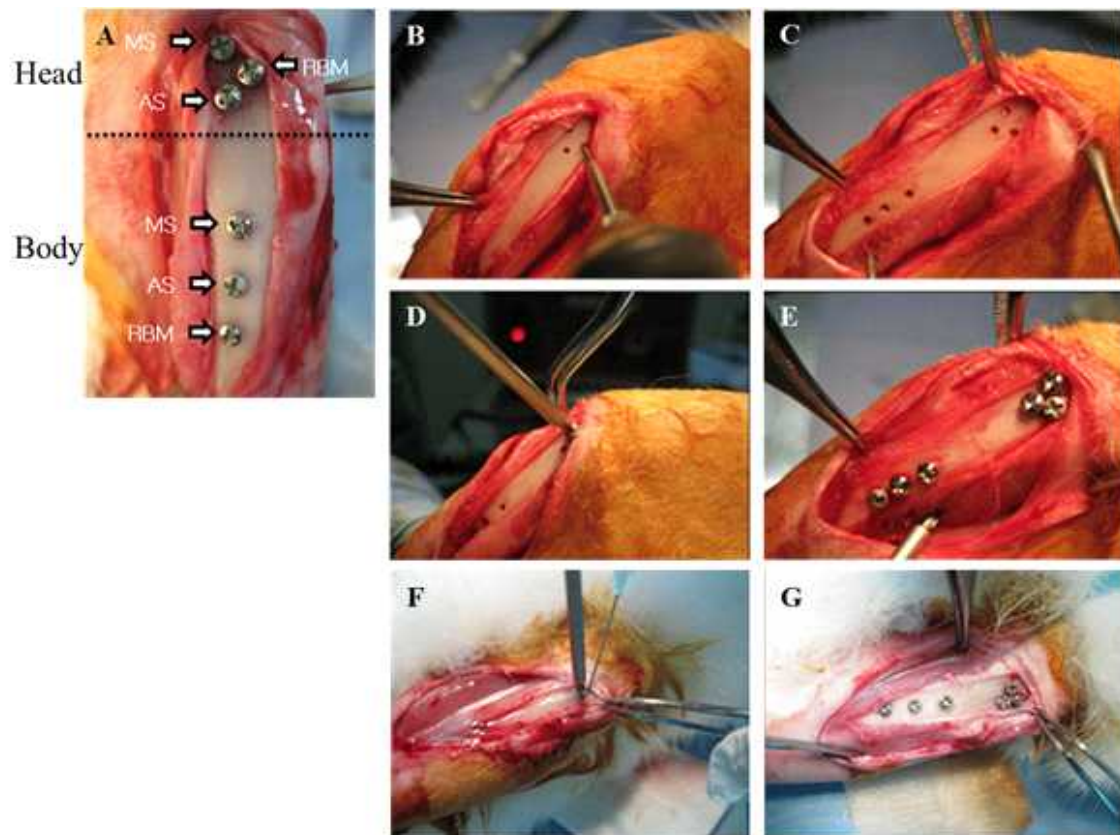


Figure 2. Locations of miniscrew (A) and insertion procedure (B-G). (A): upper part (head) and middle part (body), (B-E): pre-drilling technique, (F and G): self-tapping technique. B: pilot drilling, C: after drilling, D and F: insertion of miniscrew with manual screwdriver, E and G: after placement of miniscrews.

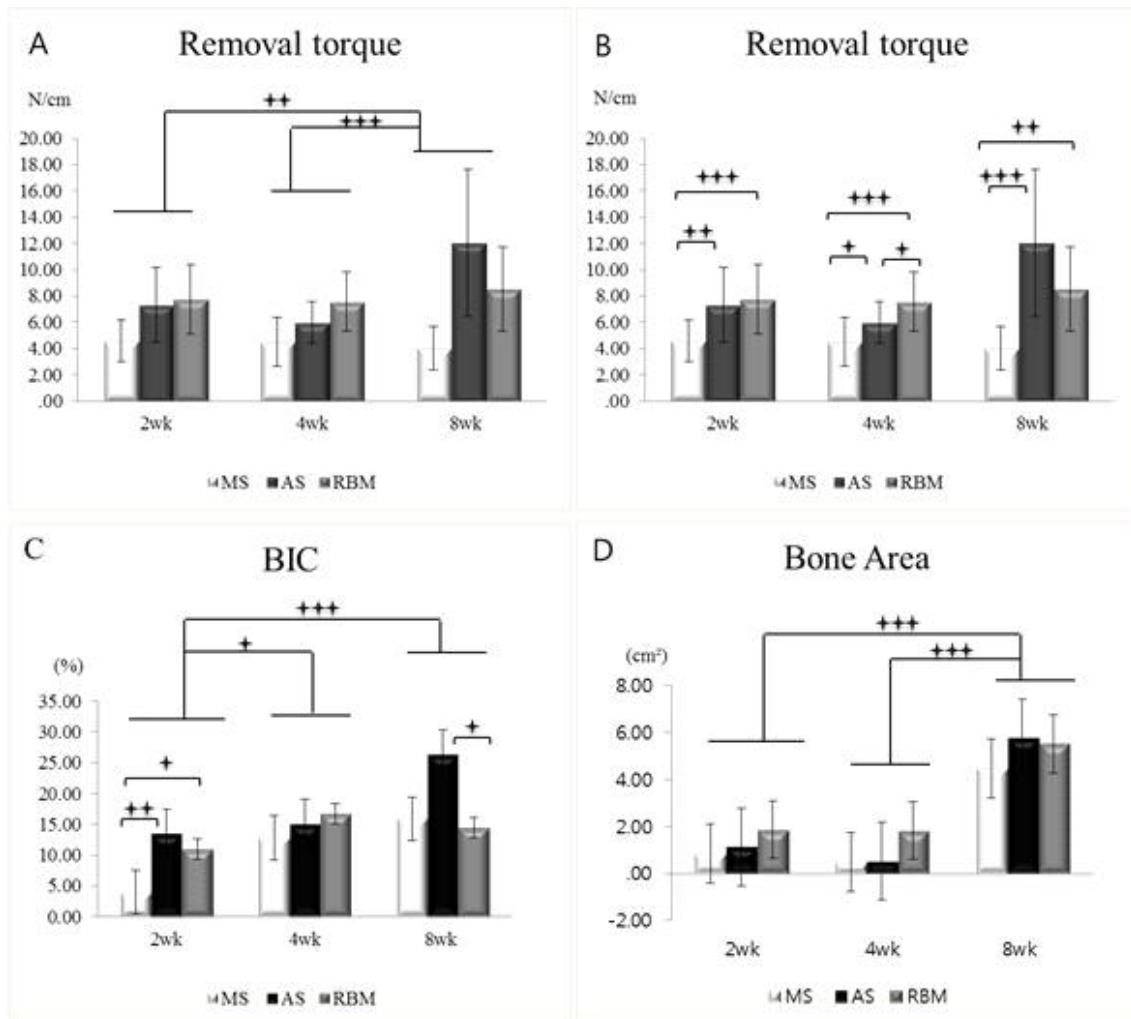


Figure 3. Removal torque (A and B), BIC ratio (C), and BA (D) of miniscrews depending on surface treatments and healing times. A: there was a statistically significant increase in removal torque in 8-week healing compared to 2- or 4- week healing; B: a significant difference of MS, AS, and RBM at 2-week, 4-week, and 8-week; (C) there was a significant increase in BIC ratio depending on healing time; (D): a significant higher BIC ratio for AS and RBM than that for MS at 2-week, and for AS than that for RBM at 8-week; (D): there was a statistically significant increase in BA depending on healing time, and there was no statistically significant difference between MS, AS, and RBM.

+: $p < 0.05$, ++: $p < 0.01$, +++: $p < 0.001$

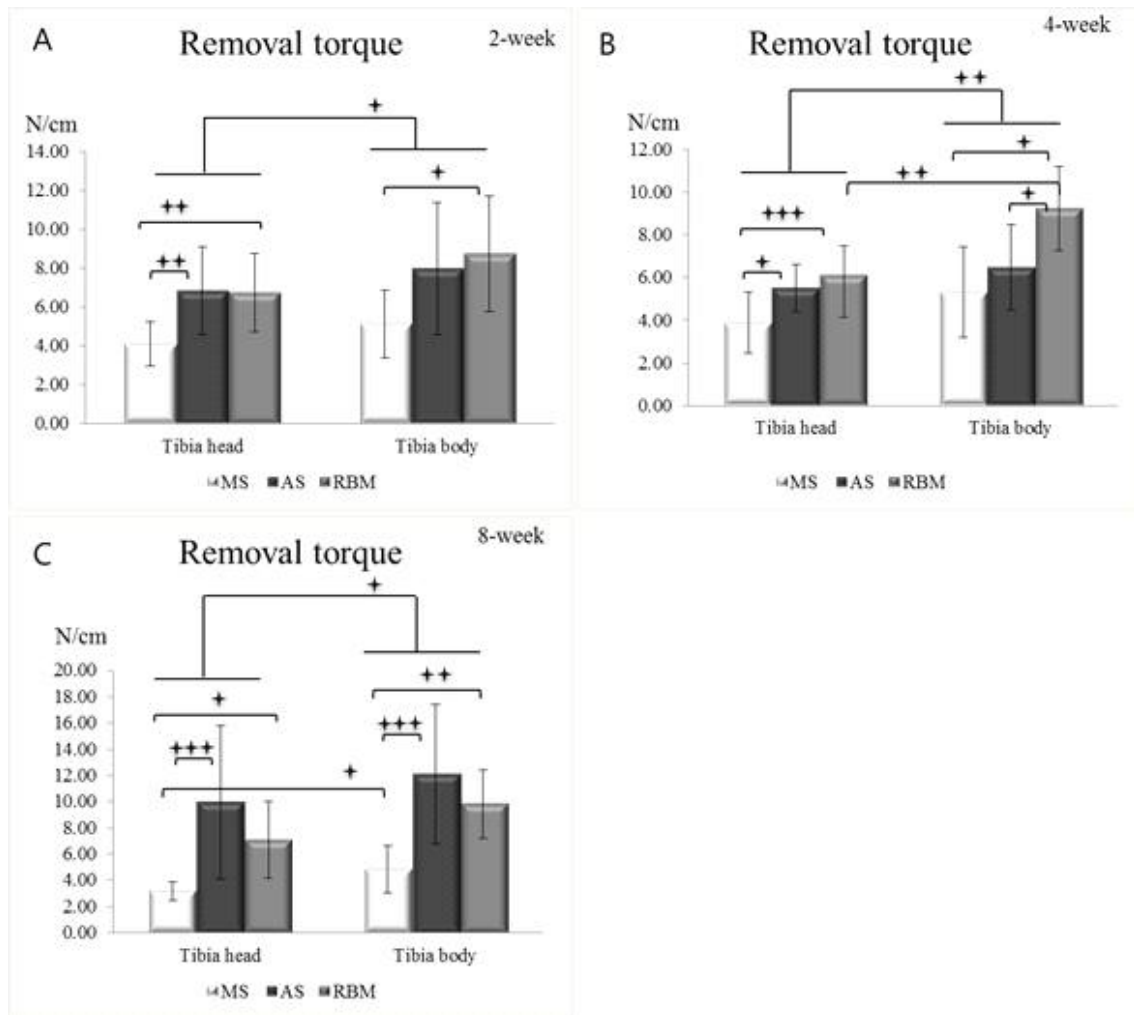


Figure 4. Removal torque of miniscrews at 2-week (A), 4-week (B), and 8-week (C) healing depending on locations. (A-C): there was significantly higher removal torque at tibia body than at tibia head.

+ : p < 0.05, ++ : p < 0.01, +++ : p < 0.001

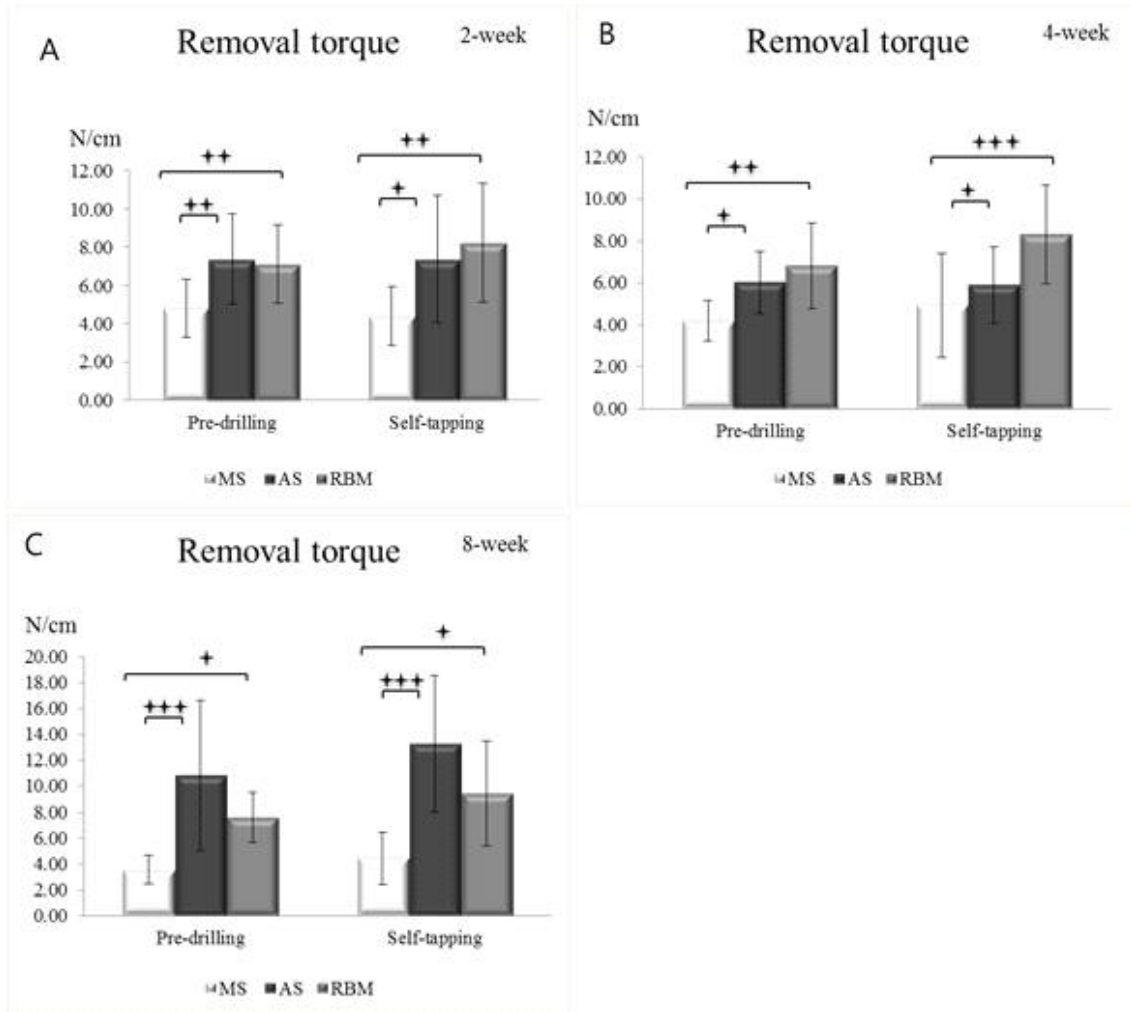


Figure 5. Removal torque of miniscrews at 2-week (A), 4-week (B), and 8-week (C) healing depending on insertion methods. (A-C): there was no statistically significant difference between pre-drilling and self-tapping.

+ : $p < 0.05$, ++ : $p < 0.01$, +++ : $p < 0.001$

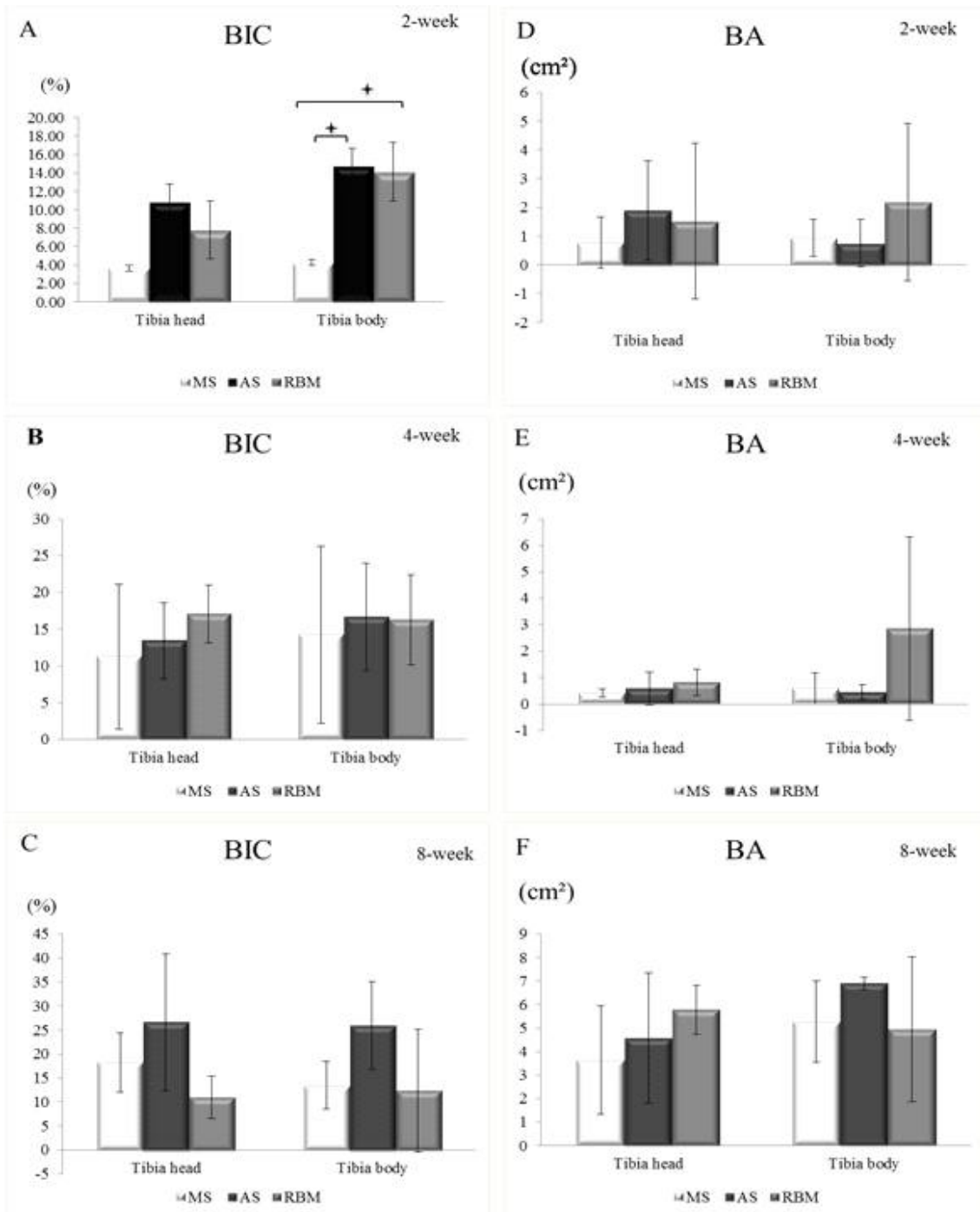


Figure 6. BIC ratio (A-C) and BA (D-F) of miniscrews regarding different locations and healing times. (A-C): there was no statistically significant difference of BIC regarding locations, (D-F): there was no statistically significant difference of BA regarding locations. (A): there was a statistically significant higher of BIC at 2-week for AS and RBM than that for MS.

+ : $p < 0.05$.

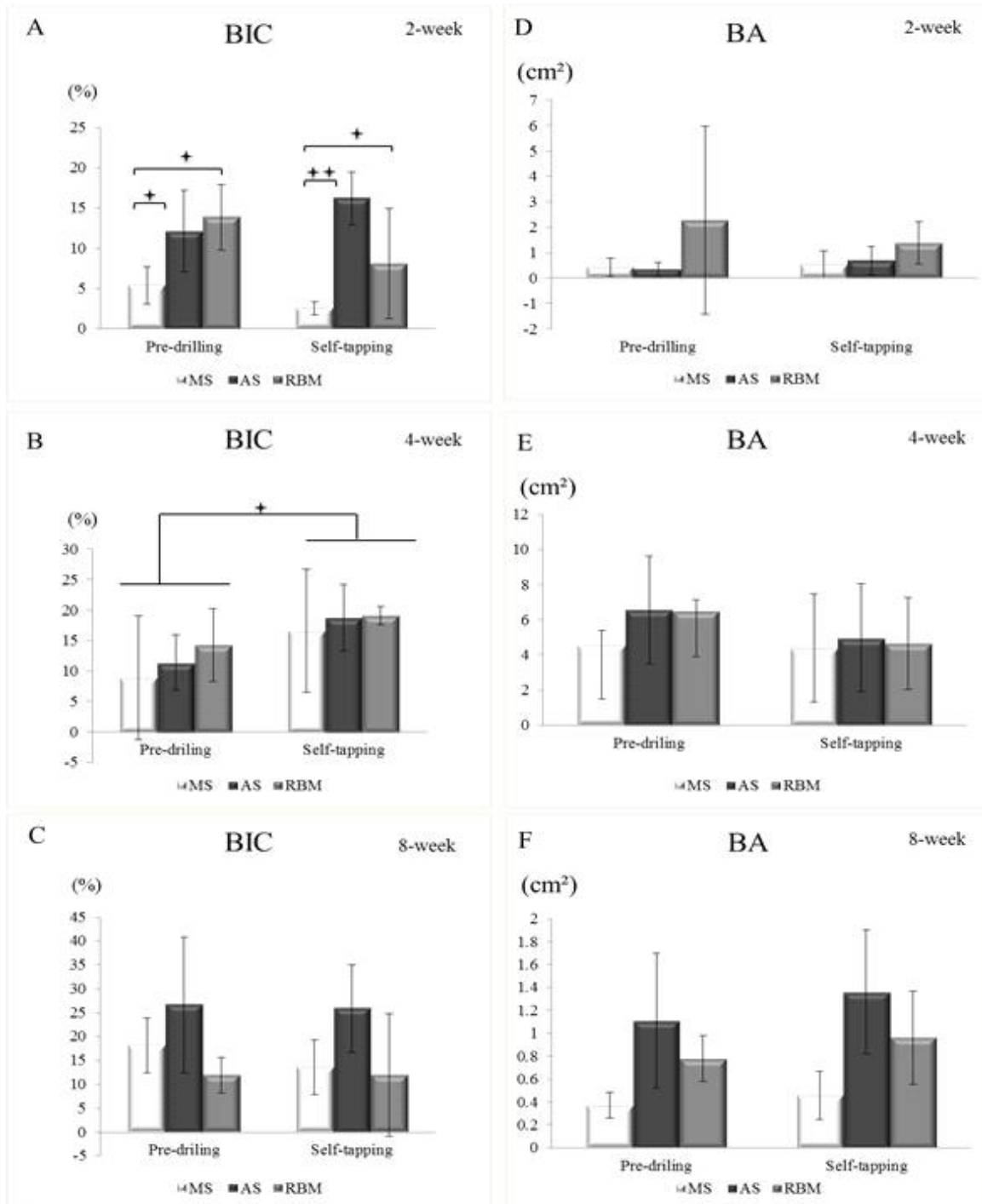


Figure 7. BIC ratio (A-C) and BA (D-F) of miniscrews depending on insertion methods and healing times. (A and C): there was no statistically significant difference of BIC regarding methods of placement, (B): there was significant higher of BIC for self-tapping than that for pre-drilling, (D-F): there was no statistically significant difference of BA regarding insertion methods.

+ : $p < 0.05$, ++ : $p < 0.01$

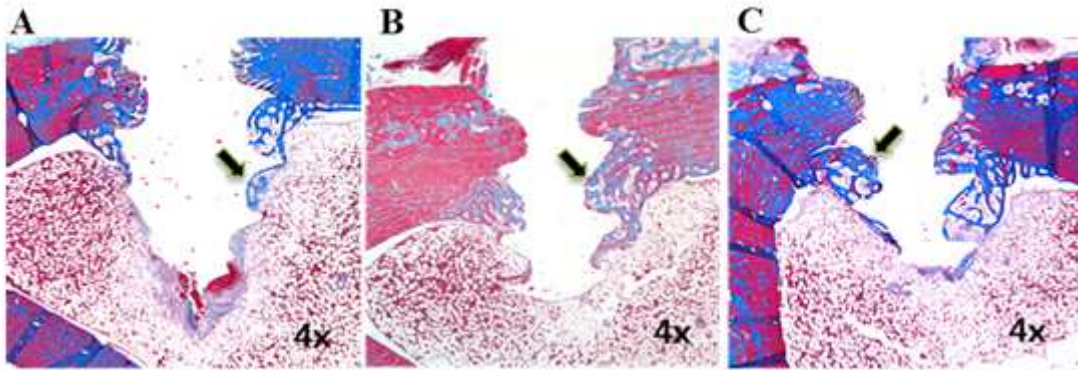


Figure 8. Histomorphometric analysis of miniscrews. (A): machine surface, (B): acid surface, (C): RBM. MT stain showed partial osseointegration of bone to miniscrew surface (arrow).

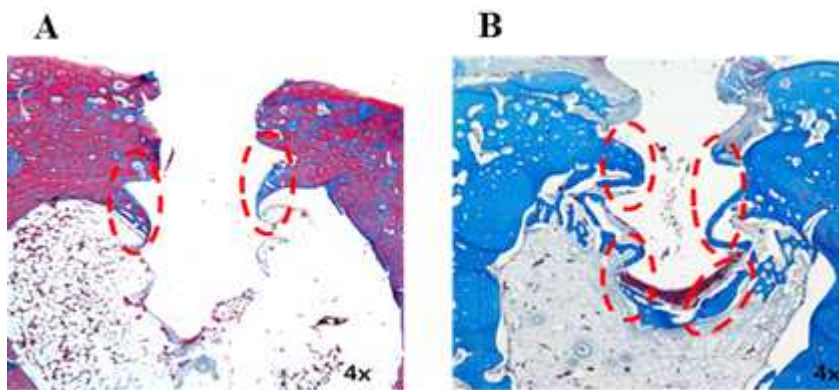
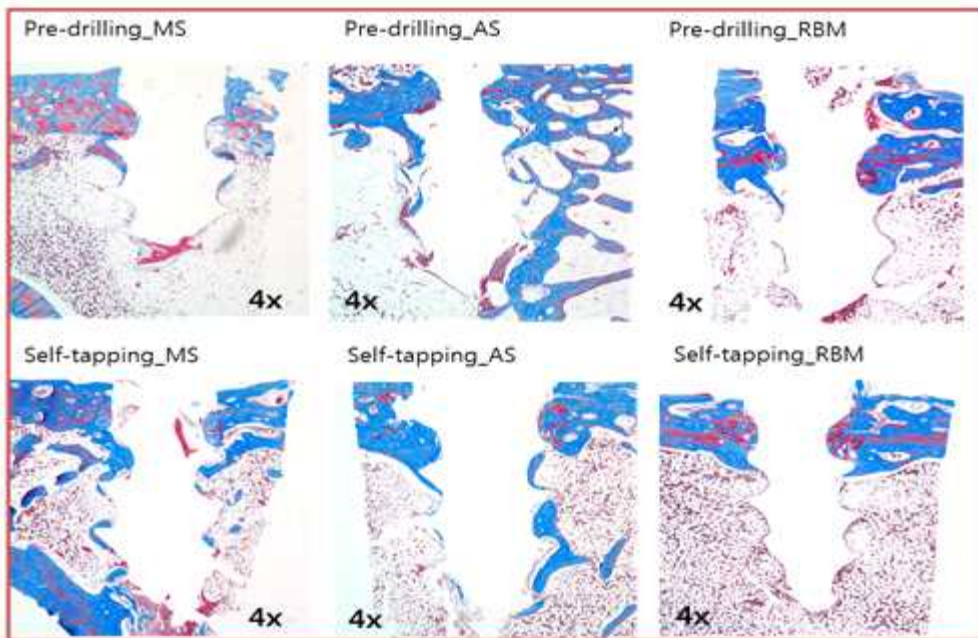


Figure 9. Histomorphometric analysis of miniscrews. (A): pre-drilling, (B): self-tapping. MT stain showed higher osseointegration of bone for self-tapping than for pre-drilling (dotted red circle).

Head of tibia



Body of tibia

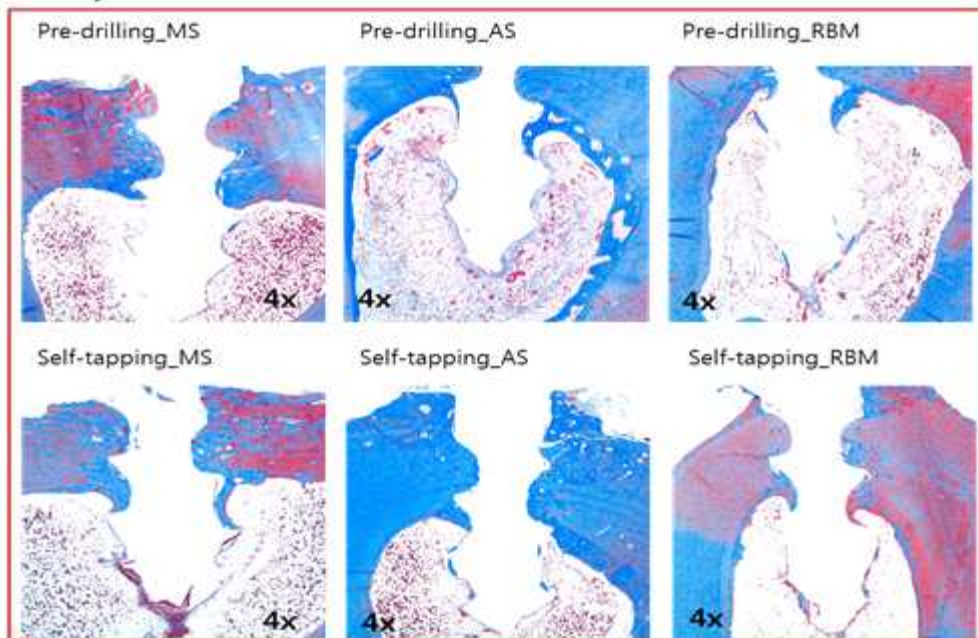


Figure 10. Histomorphometric analysis of miniscrews depending on head and body of tibia, pre-drilling and self-tapping.

국문초록

표면처리와 식립방법에 따른

미니스크류의 안정성에 대한연구

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악간 고정 또는 교정치료의 고정원으로 사용되는 미니스크류의 가공표면은 일반적으로 치조골의 피질골층과 미니스크류사이에 기계적인 압력과 마찰에 의해 안정화된다. 미니스크류의 거친 표면은 추가적인 표면의 확대와 골유착에 의해 미니스크류의 안정성을 증가시킬 수 있을 것으로 기대된다. 이 실험연구는 프리드릴링(pre-drilling) 및 셀프테핑(self-tapping)의 식립조건에서 미니스크류의 서로 다른 표면 처리에 따른 미니스크류의 안정성과 골반응을 평가하고자 하였다.

세종류의 표면처리를 한미니스크류 (직경 2mm, 길이 6 mm) (n = 204)를 뉴질랜드 백색 가토 (n=17, 무게 3kg)의 경골에 이식 하였다. 기계적 삭제 표면(MS) (n=68), 산성 처리 표면 (AS) (n=68) 및 흡수성 충격매체 처리 표면 (RBM) (n=68)의 미니스크류를 경골의 상부 (머리)와 중간 (몸체)부위에 pre-drilling과 self-tapping 방법으로 식립하였다. 식립 2, 4, 8주 후에 제거하는데 필요한 토크 (removal torque)힘을 모든 동물에서 측정하였고 두 마리의 동물은 조직학적 및 조직계측학적 분석에 사용하였다.

미니스크류를 식립하거나 제거하는 토크 측정에서미니스크류의 파절은 없었다. 9개의 미니스크류 식립 시 삽입부위의 인접 경골부위에서 미세한 골절이 발생하여 평가에서 제외을 하였다. MS의 평균 removal torque 값 (4.41 ± 1.67 N/cm)이 AS (8.34 ± 4.41 N/cm) ($p = 0.000$) 과 RBM (7.94 ± 2.75 N/cm) ($p = 0.000$)의 값보다 유의하게 낮았다. 골치유 기간에 따른 removal torque값은 식립 2 주 후 (6.57 ± 2.75 N/cm)와 4 주 후 (5.98 ± 2.26 N/cm)에서 8주 후 (8.24 ± 5.00 N/cm)보다 유의하게 통계적으로 낮았다 (각각, $p = 0.003, p = 0.000$). 모든 골치유 기간에서 경골

의 상부보다 경골의 중간부위에서 removal torque 값이 높았다. 그러나 pre-drilling 및 self-tapping 방법에 따른 removal torque 값은 통계적으로 유의한 차이가 없었다. 골접촉비율 (BIC)에서 MS ($10.88 \pm 6.10\%$)가 AS ($18.27 \pm 7.29\%$)보다 통계적으로 낮았다 ($p = 0.002$). 식립 2 주 후의 평균 BIC ($9.11 \pm 5.98\%$)가 4 주 후 BIC ($14.84 \pm 7.30\%$) ($p = 0.027$)과 8 주 후 ($18.88 \pm 10.11\%$) ($p = 0.000$)보다 통계적으로 낮았다. 식립 2주, 4 주 및 8 주 후에 경골의 상부와 중간부위 비교에서 BIC 비율의 차이가 없었지만 4 주 후 BIC값은 pre-drilling 방법에서 self-tapping 방법보다 유의하게 낮았다 ($p = 0.023$). 신생골 형성 (BA)에 있어서 MS, AS와 RBM의 통계적으로 유의한 차이가 없었지만, BA가 2주 후 ($1.30 \pm 1.69\text{cm}^2$)와 4 주 후 ($0.95 \pm 1.57\text{cm}^2$)에서 8주 후 ($5.24 \pm 2.20\text{cm}^2$)보다 유의하게 낮았다 (각각 $p = 0.000, p = 0.000$). 그러나 경골의 상부와 중간부위간의 비교에서 뿐만 아니라 pre-drilling 및 self-tapping 방법의 비교에서도 통계적으로 유의한 차이는 관찰되지 않았다.

결론적으로 높은 BIC로 인해 AS와 RBM표면은 MS보다 더 높은 removal torque 값을 보였다. Removal torque 값은 경골의 상부에보다 중간부위에서 높았고, 4 주 후 self-tapping 방법은 pre-drilling 방법보다 더 높은 BIC를 보여 self-tapping 방법이보다 더 안정된 골유착을 가진 것으로 보인다.

주요어: 표면처리, 제거터크, 미니스크류, 신생골, 골금속 접촉율

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