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An *ex vivo* study of under-drilling and osseodensification drilling

조선대학교 대학원

치의학과

서 동 준

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이 논문을 치의학 석사학위신청 논문으로 제출함

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I. 서론

해면골은 변연 피질골에 비해 임플란트 안정성에 미치는 영향이 적다. 따라서, 상악 구치부와 같이 피질골이 얇고 해면골의 골밀도가 낮은 경우 임플란트 초기 안정성의 확보가 어렵고 장기적인 임플란트 성공률도 낮다. 임플란트 초기 안정성을 높이기 위한 다양한 방법들이 개발되어 왔으며, 임상에서 가장 많이 이용하고 있는 방법이 under-drilling과 골치밀화(osseodensification) 드릴링이다.

II. 목적

본 연구의 목적은 저밀도 골에서 임플란트 초기 안정성을 높이기 위한 최적의 드릴링 방법을 찾기 위해 다양한 조건에서 under-drilling과 골치밀화 드릴링 방법을 이용하여 임플란트 안정성 평가 및 골밀도의 변화를 비교 평가하는 것이다.

III. 재료 및 방법

13개의 돼지 흉골에 87회의 임플란트 드릴링을 시행했다. 표준 방식의 드릴링, under-drilling, 그리고 반시계방향의 골치밀화 드릴링을 시행하여 임플란트를 식립하였다. 초기 안정성 평가를 위해 Osstell Mentor®와 Periotest®를 이용하여

ISQ와 PTV를 측정하였다. 드릴링된 홀 주위의 골치밀화에 대한 평가를 위해 micro-CT를 촬영하여 Hounsfield Unit (HU)을 분석하였다.

IV. 결과

같은 직경과 길이에서 골치밀화 드릴링은 표준 방식의 드릴링보다 통계학적으로 유의성이 있는 높은 ISQ와 낮은 PTV 수치를 보였다. 이는 골치밀화 드릴링의 높은 초기고정을 의미한다. 또한, 드릴링된 홀 주위에서 유의할만한 HU 수치 차이가 나타났다. 골치밀화 드릴링에서 드릴링된 홀의 주변 골에 골의 침착과 골밀도가 증가 하였음을 알 수 있었다. Under-drilling 방식에서는 표준 방식의 드릴링보다 유의성 있는 높은 ISQ와 낮은 PTV 수치를 보였으나, HU 수치의 차이는 통계학적으로 유의성이 없었다.

V. 결론

Under-drilling과 역회전을 이용한 골치밀화 드릴링 모두 임플란트의 초기 안정성을 높일 수 있는 효과적인 방식이다. 골밀도가 낮은 부위에서 골치밀화 드릴링을 이용한 임플란트 식립은 임플란트의 초기 안정성을 높일뿐 아니라, 주변 해면골의 골밀도를 증가시켜 임플란트의 골유착을 증가시키고 임플란트 성공률을 높일 수 있는 방법이다.

Key words: Biomechanics, Bone Density, Dental Implants, Implant Stability, Osseointegration

I. Introduction

Osseointegration, a prerequisite for successful implant loading, signifies a direct functional and structural union between the titanium surface and bone.[1] Osseointegration has been evaluated as the most important predictor of long-term implant success. According to Albrektsson et al.,[2] six major factors - implant design, implant surface, implant material, surgical factors such as implant primary stability (IPS), biomechanical factors such as loading conditions, and patient-related factors, including bone density, quality, and volume - play a key role in osseointegration and implant success.[3-6]

Among these, IPS is the major factor because it is related to all other categories of osseointegration.[7] IPS is successfully obtained when the micromotion of the implant is less than 50 to 150 ㎛. Micromotion above this level causes bone resorption and fibrous encapsulation around the implant, leading to implant failure rather than osseointegration.[8,9] IPS has only mechanical connection between the implant and the bone, but a biological process is observed subsequently, wherein approximately 1mm of the peripheral bone around the implant is devitalized, resorbed, and remodeled. This process will reduce the mechanical bone-to-implant contact (BIC), loosen implant stability and make the area susceptible to micromovement and fibrous integration. However, as the bone is formed, BIC increases again, which is the so-called implant secondary stability.[10,11]

IPS is considerably influenced by the quantity and quality of the bone bed.[2,12] In previous studies,[12-15] bone quality was classified by measuring Hounsfield unit (HU) values on computed tomography (CT). Type IV bone with poor bone density has higher implant failure rate than that of type I, II, and III.[12,16] This is because implants placed in bones with low-density, such as the posterior maxilla, have low primary stability and it is potentially difficult to obtain high insertion torque.[16,17]

Trabecular bone has less influence on IPS than marginal cortical bone. Therefore, implants in areas with thin cortical bones and low-density trabecular bones, such as the posterior maxilla, have the lowest success rates.[12,16] Conventional technique, an osteotomy preparation method for implant placement, is a subtractive process that cuts and extracts the bone from the implant bed. Burs of conventional technique also facilitate this removal and are manufactured with a special design (deep grooves) to store the removed bone chips between the drill flutes for potential reuse.[18] The amount of bone removed from the implant bed greatly influences IPS.[2,12]

Over the past several decades, many surgical procedures have been introduced to increase IPS in low-density bones. One of the most popular methods is the under-drilling technique. It was found that a 10% undersized preparation in low-density bone is sufficient to improve IPS, and there is no significant effect with additional reduction.[19,20] As a modification, stepped osteotomy was introduced and proved to be more effective than conventional technique.[21] According to Summers,[22] osteotomes are widely used to increase bone density and aid implant stability. The method called osseodensification technique to increase the IPS was introduced by Huwais[23].

Burs of osseodensification technique, which is non-subtractive, contain a specially designed structure with many lands that have large negative rake angles. This serves as a non-cutting edge to increase bone density when expanding the osteotomy and allows the bone to be preserved. These burs are designed to have a tapered shank and a cutting chisel edge allowing the osteotomy to be expanded and the diameter to be gradually increased as the burs enter deeper. They can be rotated clockwise (cutting direction) to drill bone or counter-clockwise (non-cutting direction) to smoothly compact bone.[23]

Although many studies have been reported,[23-25] there are only few reports comparing various drilling techniques or densification objectively. The aim of this study is to identify a method that can maximize IPS and bone density in low-density bones by objective evaluation using various drilling techniques (under-drilling technique and osseodensification technique).

II. Material and Methods

Bone sample and experimental groups

We prepared 13 pig sternums for 87 implant drillings. All bone samples included trabecular bones only to exclude the effect of cortical bone, and were drilled with a distance between the holes at least 3 mm.

The experiment was conducted with IPS test and bone density test. IPS test was divided into two groups: standard drilling (drilling up to the same size as the implant diameter) and under-drilling. Each group was further subdivided, based on the drilling technique, into three subgroups: conventional technique (CD), osseodensification technique (OD) in the clockwise direction (OD-C), and OD in the counter-clockwise direction (OD-CC). The sample size for IPS test was 10 for each group (n=10).

Bone density test was divided into three groups: CD, OD-C, and OD-CC. In this, each group was subdivided into three subgroups and drilling was performed with 1 mm a difference in diameter (standard, +1 mm, and +2 mm). The sample size for bone density test was 3 for each group (n=3).

Implant bed preparation and implant installation

Implant bed was prepared according to the manufacturer’s recommendations. The drilling speed was 1400 RPM and insertion torque was 50 Ncm for CD and OD-C groups, 800 RPM and 30 Ncm for OD-CC group.

60 Osstem tapered implants (TSIII SA pre-mounted, OSSTEM IMPLANT CO. LTD, Seoul, Korea), with 4.5 mm diameter and 10 mm length were installed for IPS test with a drilling speed of 50 RPM and insertion torque of 50 Ncm.

Evaluation of implant primary stability

Depending on the manufacturer, the actual diameter, length, and taper of the burs are different. Since these conditions affect the IPS after implant insertion, the actual diameter, length, and taper of the burs used were adjusted within the 0.2 mm error range

Osstem tapered burs (TPD3C, OSSTEM IMPLANT CO. LTD, Seoul, Korea), with final 4.3 mm (standard drilling), 3.8 mm (under-drilling) major diameter and 10 mm length (TPD3C4510, TPD3C4010), were used for CD and Versah universal tapered burs (VT, Versah LLC, MI, USA), with final 4.3 mm (standard drilling), 4.0 mm (under-drilling) major diameter and 10 mm length (VT3848, VT3545), were used for OD.

IPS was evaluated using two methods: Resonance frequency analysis (RFA) and Periotest. Immediately after the implant insertion, the periotest value (PTV) was evaluated, using the Periotest device (Periotest® M, Medizintechnik Gulden e.K., Modautal, Germany) and the implant stability quotient (ISQ) was tested using the Osstell device (Osstell® ISQ, OSSTELL, Göteborg, Sweden), in each group of IPS test. PTV and ISQ were randomly measured twice per implant.

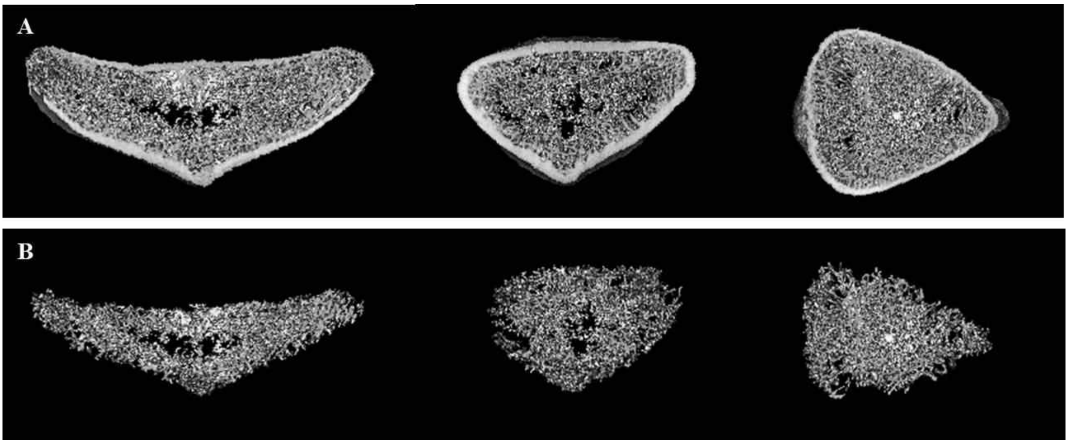

Figure 1. Micro-positron emission tomography/computed tomography images of the sternum. A: Total bone, B: Trabecular bone.

Evaluation of bone density

Drilling with 1 mm a difference in diameter was performed without any adjustment of length or diameter according to the manufacturer's instructions.

Osstem tapered burs (TPD3C, OSSTEM IMPLANT CO. LTD, Seoul, Korea), with final 3.8 mm, 4.8 mm, 5.8 mm major diameter and 10 mm length (TPD3C4010, TPD3C5010, TPD3C6010), were used for CD of bone density test and Versah universal tapered burs (VT, Versah LLC, MI, USA), with final 3.5 mm, 4.5 mm, 5.5 mm major diameter and 10 mm length (VS3238, VS4248, VS5258), were used for OD.

Bone density of the implant bed was scanned using a micro-positron emission tomography/computed tomography (CT) scanner (Quantum GX, PerkinElmer Inc., MA, USA). Image scanning conditions were as follows: 90 kV voltage, 80 μA current, 45 mm field of view (FOV), 4 minutes exposure time, and 90 μm voxel size. Scanned images were obtained using Quantum Image Viewer software (Quantum GX SimpleViewer, PerkinElmer Inc., MA, USA). BMD of the samples was measured using biomedical imaging analysis software (Analyze 12.0, AnalyzeDirect Inc., KS, USA). The total mean BMD value of the sternum including the cortical and trabecular bone was 131.57 ± 10.14 mg/cm^3 (Figure 1). The difference in HU between the implant hole and peripheral bone was measured in each group of bone density test and subdivided into coronal (1 mm distance from the upper surface), middle (5 mm distance), and apical (9 mm distance) areas. The region of interest was identified as the surrounding bone to a distance 1 mm from the surface of the hole and it was measured 10 times per group (Figure 2).

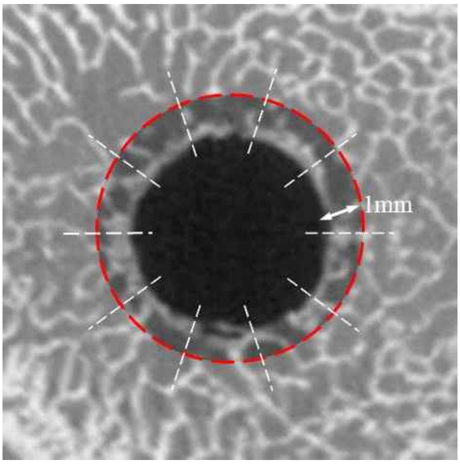

Figure 2. The region of interest to measure the difference in Hounsfield unit of bone density test.

Statistical analysis

ISQ values, PTVs, and HU gaps of the coronal area at each diameter step were statistically compared among groups using the non-parametric test, the Kruskal-Wallis test, and the Mann-Whitney test. Statistical comparison of HU values of the middle and apical areas at each diameter step was analyzed using one-way analysis of variance with Tukey’s post-hoc test (ANOVA). Statistical analysis was performed using the SPSS software (SPSS 20.0, IBM Corp., NY, USA). Statistical significance was set at $P < 0.05$.

III. Results

Implant primary stability

Under-drilling with OD-CC (ISQ: 81.25 ± 3.09, PTV: -7.67 ± 0.47) had the highest value of IPS with statistical significance ($p < 0.05$) and standard drilling with CD (ISQ: 66.35 ± 2.11, PTV: -4.38 ± 1.58) showed the lowest IPS among all groups. Under-drilling groups showed higher IPS than standard drilling groups, regardless of drilling techniques ($p < 0.05$). The IPS values of the OD-CC group were the highest in the standard and under drilling groups. Under-drilling with CD (UD) (ISQ: 74.25 ± 2.10, PTV: -6.23 ± 0.87) had higher IPS compared to standard drilling with OD-CC (ISQ: 71.25 ± 2.57, PTV: -6.10 ± 0.87) with statistical significance on ISQ ($p < 0.05$), but not on PTV (Tables 1-2).

Table 1. Implant stability quotient values in groups

Group			ISQ value	Comparison between groups*
A	Standard drilling	CD	66.35 ± 2.11	C, D
B	Standard drilling	OD-C	67.85 ± 3.59	C, E
C	Standard drilling	OD-CC	71.25 ± 2.57	A, B, D, F
D	Under drilling	CD	74.25 ± 2.10	A, C, F
E	Under drilling	OD-C	78.30 ± 3.83	B, F
F	Under drilling	OD-CC	81.25 ± 3.09	C, D, E

*Significant difference between the groups ($p < 0.05$). ISQ: Implant stability quotient, CD: Conventional technique, OD-C: Osseodensification technique in the clockwise direction, OD-CC: Osseodensification technique in the counter-clockwise direction.

Table 2. Periotest values in groups

Group			PTV	Comparison between groups*
A	Standard drilling	CD	-4.38 ± 1.58	C, D
B	Standard drilling	OD-C	-5.49 ± 1.51	E
C	Standard drilling	OD-CC	-6.10 ± 0.87	A, F
D	Under drilling	CD	-6.23 ± 0.87	A, F
E	Under drilling	OD-C	-7.02 ± 0.98	B, F
F	Under drilling	OD-CC	-7.67 ± 0.47	C, D, E

*Significant difference between the groups ($p < 0.05$). PTV: Periotest value, CD: Conventional technique, OD-C: Osseodensification technique in the clockwise direction, OD-CC: Osseodensification technique in the counter-clockwise direction.

Bone density

Regardless of the difference in diameters, OD-CC groups had higher HU gaps than the CD and OD-C groups ($p < 0.05$), in all areas (coronal, middle and apical area). There was no statistical difference in diameters between CD and OD-C groups. In OD-CC, larger the drilling diameter, the higher the HU gap, in all areas, indicating that it was the highest for 5.5 mm diameter. But this was significant only between 3.5mm and 5.5mm ($p < 0.05$) (Table 3).

Regardless of diameter, apical values were significantly highest values in all OD-CC groups ($p < 0.05$). There were no significant differences between the coronal and middle areas. There were no statistical differences in any area between the CD and OD-C groups. Comparing OD-C and OD-CC groups, there was a difference of minimum 43 HU in the middle area with 3.5 mm diameter, and maximum 180 HU in the apical area with 5.5 mm diameter (Figures 3-6).

Table 3. Hounsfield unit gaps in groups

		Coronal area	**Middle area**	**Apical area**
CD	**3.8 mm**	587.50 ± 65.24	572.50 ± 84.17	583.33 ± 83.39
	4.8 mm	604.17 ± 71.94	610.83 ± 61.48	615.00 ± 87.74
	5.8 mm	615.84 ± 61.41	595.00 ± 87.94	582.50 ± 81.25
OD-C	**3.5 mm**	602.50 ± 69.28	604.17 ± 61.97	606.67 ± 63.29
	4.5 mm	588.33 ± 64.57	611.67 ± 72.14	611.67 ± 75.64
	5.5 mm	605.83 ± 82.44	603.33 ± 69.09	596.67 ± 86.29
OD-CC	**3.5 mm**	648.33 ± 76.26	647.50 ± 59.94	704.17 ± 52.56
	4.5 mm	672.50 ± 76.38	690.00 ± 75.89	745.83 ± 74.30
	5.5 mm	685.00 ± 59.67	714.17 ± 73.01	776.67 ± 79.31

CD: Conventional technique, OD-C: Osseodensification technique in the clockwise direction, OD-CC: Osseodensification technique in the counter-clockwise direction.

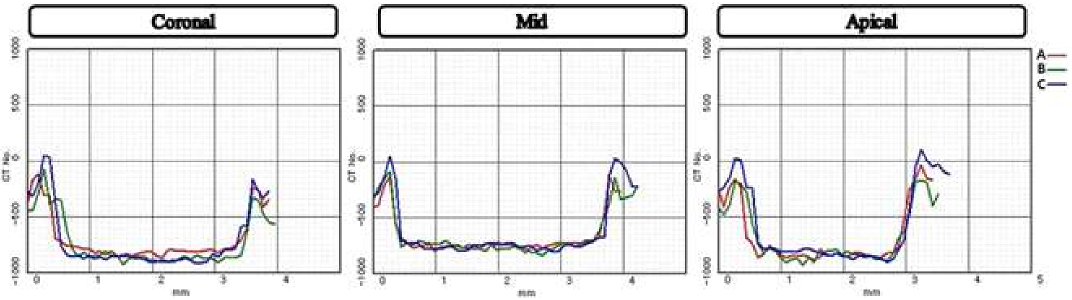

Figure 3. Comparison of Hounsfield unit gaps according to area at 3.8 mm diameter of conventional technique and 3.5 mm diameter of osseodensification technique. A: conventional technique, B: osseodensification technique in the clockwise direction, C: osseodensification technique in the counter-clockwise direction.

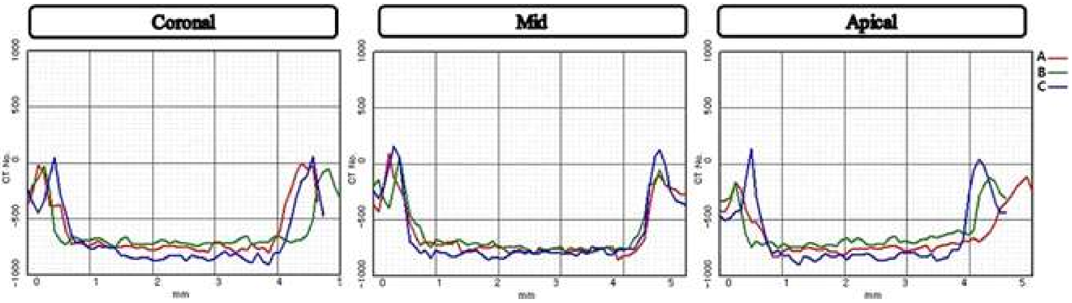

Figure 4. Comparison of Hounsfield unit gaps according to area at 4.8 mm diameter of conventional technique and 4.5 mm diameter of osseodensification technique. A: conventional technique, B: osseodensification technique in the clockwise direction, C: osseodensification technique in the counter-clockwise direction.

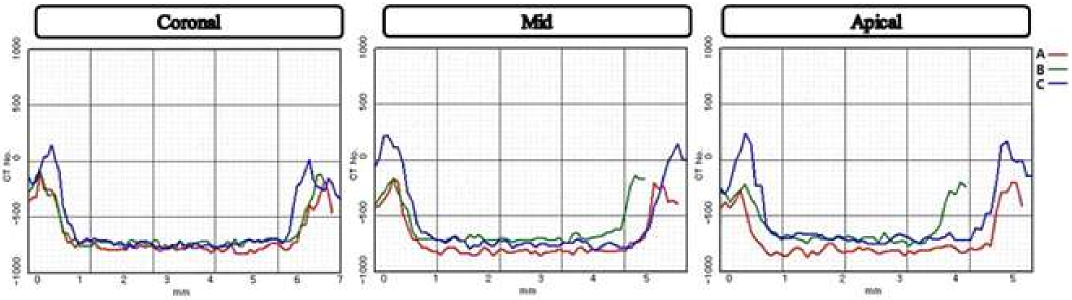

Figure 5. Comparison of Hounsfield unit gaps according to area at 5.8 mm diameter of conventional technique and 5.5 mm diameter of osseodensification technique. A: conventional technique, B: osseodensification technique in the clockwise direction, C: osseodensification technique in the counter-clockwise direction.

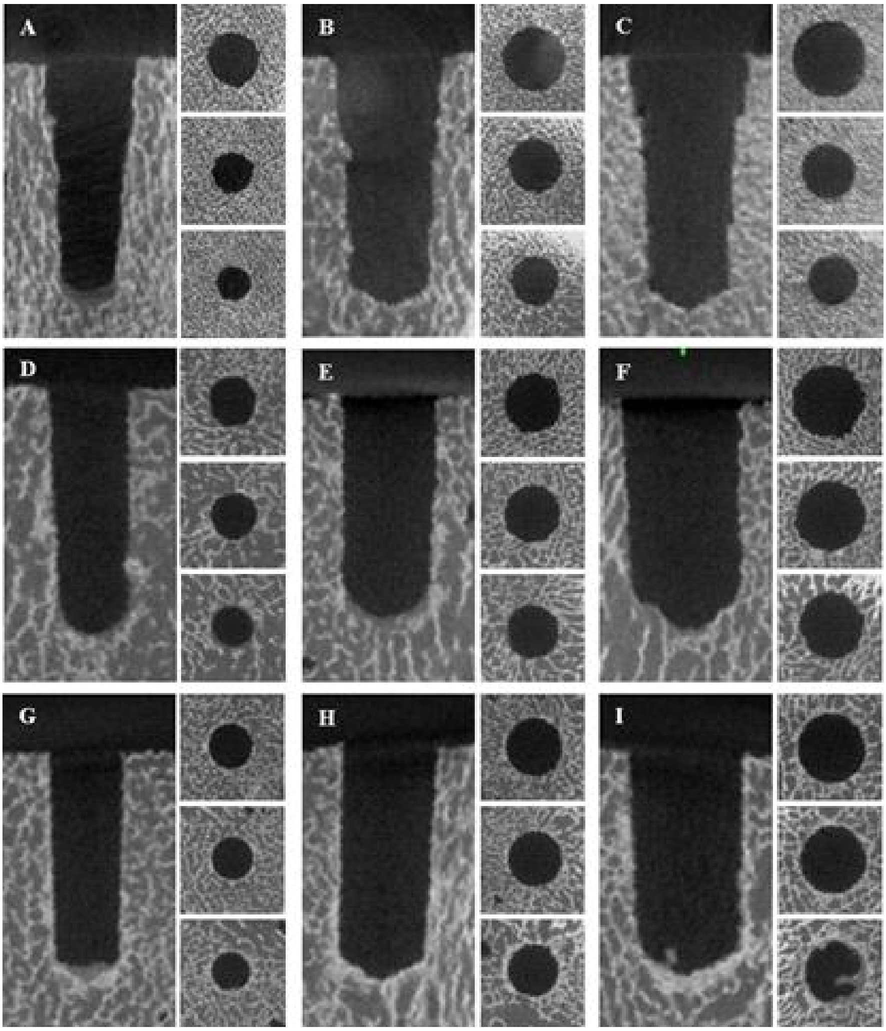

Figure 6. Comparison of bone density around the drilling holes on micro-positron emission tomography/computed tomography images according to diameters and techniques. A: conventional technique (CD) with 3.8 mm drilling, B: CD with 4.8 mm drilling, C: CD with 5.8 mm drilling, D: osseodensification technique in the clockwise direction (OD-C) with 3.5 mm drilling, E: OD-C with 4.5 mm drilling, F: OD-C with 5.5 mm drilling, G: osseodensification technique in the counter-clockwise direction (OD-CC) with 3.5 mm drilling, H: OD-CC with 4.5 mm drilling, I: OD-CC with 5.5 mm drilling.

IV. Discussion

According to previous studies,[26-28] the distal tibia and radius had a value of 169 ± 34 mg/cm³ and 160 ± 33 mg/cm³. The measurements of the thoracic spine (Th10) and lumbar spine (L4) showed a value of 90.4 ± 28.9 mg/cm³ and 80.8 ± 32.4 mg/cm³. A value of 295.2 ± 93.6 mg/cm³ and 293.4 ± 112.1 mg/cm³ were observed in the right and left maxillary posterior regions. The sternums (131.57 ± 10.14 mg/cm³) used in this study corresponded to low-density bone. Oliveira et al.[13] and Lindh et al.[14] analyzed CT to evaluate the mandibular and maxillary bones, and measured the density (HU) of only trabecular bone without cortical bone. They explained that the values of bone type IV were less than +200 HU, those of types II and III were between +200 HU and +400 HU, and those of type I were larger than +400 HU. The increase in the HU gap indicated an increase in bone condensation in the peripheral and apical areas, which led to an improvement in BMD. The density of air was equal to -1000 HU, water to 0 (zero) HU in our study. Although it is difficult to make an absolute comparison with the values of those studies, it can be explained that the bone density was increased because the gap values were increased. Because of the effect of osseodensification technique, the gap of HU was increased by a minimum of 43 HU and a maximum of 180 HU. These results show that the poor density bone such as type IV can be changed to densified bone such as type II or III. Type II and III bones are better factors in implant success than type IV bone.

Clinically there are three methods to measure implant stability: insertion torque measurement, RFA, and periotest. The IPS is directly correlated with the implant insertion torque. According to Norton,[29] an implant insertion torque of 25 Ncm is sufficient for clinically successful primary stability. However, in the case of immediately loaded implants, at least 32 Ncm insertion torque is required and 45 Ncm is needed in sites of low-density bone.[30,31] Moreover, a high insertion torque (> 50 Ncm) causes microfracture or bone necrosis of the peri-implant bone area in the early healing stages, which may weaken the primary stability and result in implant failure.[32] Implant torque can be measured using a digital torque wrench or implant motor, but it can only be measured at the time of implant insertion.[3]

RFA and periotest have been proposed to clinically evaluate implant stability because of their reproducibility.[33] Periotest is measured as the contact time of the device during repetitive percussion between the tapping rod and implant. RFA is measured electromagnetically as ISQ unit, which means the resonance frequency caused by excitation of a small implant peg attached to the implant.[34] Generally, RFA seemed to be more accurate than periotest.[35]

Huwais et al.[23] invented a denser bur, which can be rotated counter-clockwise (non-cutting direction) to smoothly compact bone, or clockwise (cutting direction) to drill bone. According to a previous study,[23] osseodensification technique shortened the healing period. The viscoelastic/plastic mechanism created by the load applied to the bone, which is made by this special bur, causes compaction of the bone. This technique demonstrates an increase in insertion torque from 25 Ncm, measured by conventional technique, to 49 Ncm in low-density bones.[23] The residual strains of viscoelasticity create a compressive forces against the surface of implants, called the spring back effect, which increases IPS and BIC.[36]

The preparation of osseodensification technique should start with a smaller diameter than conventional technique because of the recovery of elastic strain. Owing to its special design and usage, a condensed autografted bone layer is created around the periphery and at the apex of the hole.[37,38]

If the hole of the osseodensified osteotomy remained empty, the hole diameter was decreased by 91%. It is important to obtain a high IPS and BIC for osseointegration of implants.[23] When osseodensification technique was used, the diameter of the osteotomy site became smaller, the boundary of the osteotomy site became more condensed in the scanning electron microscope and micro-CT images, and the rate of contact between the bone and implant surface became three times higher. The densification of the bone does not occur in the cortical bone as it lacks elasticity. Similar results were obtained in this study. The gap of HU in the bone using osseodensification technique in the counter-clockwise direction was greater than that using conventional technique and osseodensification technique in the clockwise direction. It explains more bone compaction and higher BMD. This is probably because osseodensification burs deposit bones rather than subtract during counter-clockwise rotation.

Almutairi et al.[24] evaluated the effect of osseodensification technique on IPS and compared it with conventional technique. 48 implants with a different thread design were inserted into the head of a cow femur using conventional technique and osseodensification technique. The PTVs were measured to evaluate the IPS. There was no statistically significant difference in the PTV between conventional technique and osseodensification technique. The PTV of conventional technique was better than that of osseodensification technique. This may be because osseodensification technique is not useful in dense, compact bones such as Type I and II. It was shown that osseodensification technique is ineffective and not essential when the quality and quantity of the bone bed is good. In this study conducted in low-density bone, osseodensification technique had a higher IPS than conventional technique, regardless of the direction. In particular, IPS of osseodensification technique in the clockwise direction was higher than conventional technique even under the same conditions controlled. This means that the design of osseodensification bur is more effective to increase IPS than conventional bur.

Cáceres et al.[25] investigated the effect of osseodensification technique on ISQ, insertion torque, and removal torque in pig tibia bones. One hundred osteotomies were performed and osseodensification technique was compared to conventional technique. Insertion and removal torque were measured manually using an analog Torque Gauge. All osseodensification technique values were significantly higher than those of conventional technique. It was concluded that osseodensification technique increases the ISQ, insertion torque, and removal torque, which means a high IPS.

Experiments of this study were conducted in low-density bone. It was concluded that osseodensification technique has a better effect in low-density bone on ISQ and PTV, increasing IPS than conventional technique. In addition, osseodensification technique creates an increase in BMD of low-density bone by condensing the bones around the implant, based on the increased value of HU compared to conventional technique and under-drilling technique. It was proved that under-drilling technique has a better effect on IPS than conventional technique, but there is no difference in BMD. Higher IPS and better BMD increase osseointegration and lead to implant success.

Although this study is worth to objectively assess implant primary stability and bone density in the controlled conditions in low-density bones, there are limitations in evaluating only primary stability through *ex vivo* study. Further long-term clinical studies are needed on how the deposited and condensed bone by the osseodensification technique affects secondary stability for implant success.

V. Conclusion

In this study, the implant primary stability and bone density were evaluated using various drilling techniques in low-density bones, and the conclusions are as follows: 1) Osseodensification technique and under-drilling technique increased the implant primary stability compared to conventional drilling technique. 2) The conventional technique and osseodensification technique in the clockwise direction did not deposit bone around the implant holes. 3) Osseodensification technique in the counter-clockwise direction increased not only the implant primary stability, but also the bone density around the implant holes.

VI. References

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