The Effects of Ion Beam–Assisted Deposition of Hydroxyapatite on the Grit-blasted Surface of Endosseous Implants in Rabbit Tibiae

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Purpose: *This study was undertaken to evaluate ion beam–assisted deposition (IBAD) of hydroxyapatite (HA) on the grit-blasted surface of endosseous dental implants 6 weeks postplacement.* ***Materials and Methods:*** *A total of 40 implants was placed in the tibiae of 10 New Zealand white rabbits. Twenty implants were grit-blasted only and the other 20 were grit-blasted and coated with HA by the IBAD method. After 6 weeks of healing, the rabbits were sacrificed and removal torque tests, histomorphometry, and morphometric analysis of microtomographic images were performed.* ***Results:*** *The HA-coated group showed significantly higher removal torque, bone-to-implant contact, and bone volume than the other group.* ***Discussion and Conclusion:*** *In a previous study, the authors suggested that HA coating deposited on a machined surface by the IBAD method showed results comparable to or more favorable than the results obtained with a blasted surface. This study indicated that the HA coating produced by the IBAD method was also very effective on the aluminum oxide–blasted surface, as demonstrated by the early formation of osseointegration. Morphometric analysis by microtomography showed some promise in measuring the osseointegration rate.* (More than 50 references.) Int J Oral Maxillofac Implants 2005;20:31–38

Key words: *hydroxyapatite, implant surfaces, ion beam-assisted deposition, microtomography, osseointegration*

The development and expanded use of endosseous dental implants over the last 2 decades has been remarkably rapid.[1] While the use of hydroxyapatite (HA) -coated endosseous dental implants has gained in popularity over the past 10 years, the short-term and long-term predictability and indications for their use remain highly controversial.[2] Some reports suggest that the HA coating may separate from the substructure, undergo dissolution in tissue fluids, and/or contribute to rapid osseous breakdown around the implant.[3–6] Other reports, however, relate favorable responses to HA-coated implants, which include rapid bone adaptation to the HA, greater stability at uncovering, and increased coronal bone growth.[7–11] The contradictions may be related to differences in chemical composition of the HA on the implant surface,[2] and therefore failure may be related to compositional and structural changes of the coating,[12] which are dependent on coating method.

HA coating can be applied on metal implants by numerous methods, including electrophoretic deposition,[13] dip coating,[14] hot isostatic pressing,[14] flame spraying,[15] plasma spraying,[16,17] and pulsed laser deposition.[18] Currently, no universal standard manufacturing guideline exists for depositing HA on implant surfaces.[19] The most commonly used plasma spraying methods have some problems, ie, chemical nonuniformity of the coating layer and degradation

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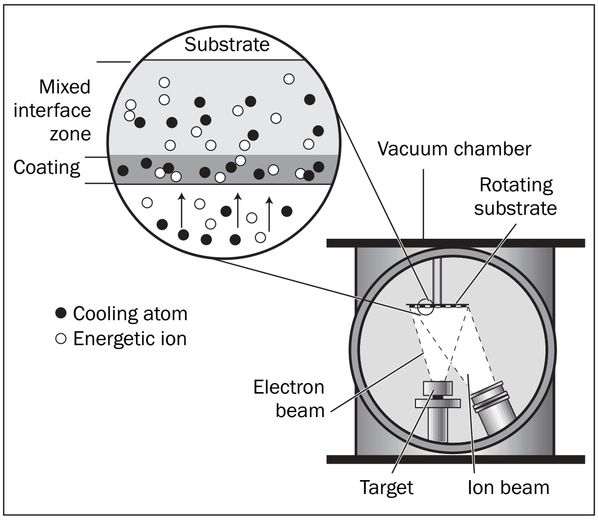

Fig 1 Schematic drawing of IBAD system.

in the human body. Also, low adhesion strength between metal and HA coating remains a problem, which is not acceptable in the fields of orthopedics and dental applications.[20,21]

Of the several coating methods being recently developed to resolve these problems, ion beam–assisted deposition (IBAD), a method that was introduced in previous studies,[22,23] has shown promise.[20] The HA coating on the as-machined surfaces has shown outcomes comparable to or more favorable than those obtained with grit-blasted implants.[22] Thus, the authors hypothesized that combining the blasted surface and HA deposition by IBAD method would have synergistic effects. Therefore, in the present study, implants with a grit-blasted surface were coated with HA using the IBAD method and compared to grit-blasted implants of the same type without HA coating. The aims of this study were to evaluate the effects of HA coating on the grit-blasted surface of endosseous dental implants and determine whether early osseointegration of implants with such HA coating can be realized.

MATERIALS AND METHODS

Hydroxyapatite Coating

Evaporants used for coating were made by adding 17.5% mass ratio of calcium oxide (CaO) powder (Cerac, Milwaukee, WI) to HA powder (Alfa Aesar, Ward Hill, MA). The mixture was ball milled in ethyl alcohol for 24 hours, with aluminum oxide (Al_2O_3) balls as media. The powder mixtures were then sintered in air at 1,200°C for 24 hours to make evaporants. Figure 1 shows a schematic diagram of the IBAD system employed in this study. Roughing evacuation was done using a mechanical rotary pump to acquire 5×10^{-2} mmHg and maintained down to 10^{-7} mmHg using a cryopump (Helix Technology, Mansfield, MA). Before deposition, the surface of the implants was cleaned for better adhesion with an ion beam (120 V, 2 A) extracted from an end-hall-type ion gun (Mark II, Commonwealth Scientific, Alexandria, VA). For the evaporation, voltage of the electron beam (Telemark, Fremont, CA) was 8.5 kV, the current was initially 0.06 to 0.08 A and was increased to 0.15 A. The substrate holder was rotated at a speed of 8 rpm during the deposition for uniformity of the coating layer. The thickness of the coating layer, which was measured by a surface profiler (Model P-10; Tencor, Santa Clara, CA) was 1 µm.

Experimental Animals

Ten female adult New Zealand white rabbits (average age 15 months old, average weight 3 kg) were used. Throughout the study the animals were kept in separate double cages and were fed with standard food.

Implants and Coating Process

Forty commercially pure titanium screw-type implants 7 mm in length and 3.75 mm in diameter (Osstem, Seoul, Korea) were used. All 40 implants were blasted with Al_2O_3 particles (mean particle size of 50 µm) at a pressure of 4 to 5 kg. The implants were then divided into 2 groups. The implants of group 1 (n = 20) were set aside; the implants of group 2 (n = 20) were coated with HA using the IBAD technique for coating deposition. The roughness profile was obtained using a surface profiler, and various roughness parameters could be automatically obtained from the computer analyses. Mean values for surface roughness (Ra) were similar for the 2 groups (5.8 µm for group 1 and 5.7 µm for group 2, (Fig 2).

Implant Placement

In each rabbit, 2 mL/kg of 50 mg/mL ketamine (Ketalar; Yuhan, Seoul, Korea) was injected intramuscularly for general anesthesia, and 2% lidocaine (Yuhan) with epinephrine (1:100,000) was administered under aseptic conditions at the surgical site.

A skin incision was made on the right and left sides of the rabbit tibia, and a flap was created to expose the tibia. On the medial anterior side of each tibia, 2 experimental implants of the same kind were placed. Both kinds of implants were placed in each rabbit, randomly placed in either the left or right tibia. The implants were placed at a distance of 1 cm apart, and the drilling and placement were done with copious saline irrigation. Tapping was limited to

Fig 2 Sample implants from group 1 *(left)* and group 2 *(right)*.

Fig 3 Torque strain gauge used.

the cortical bone and initial fixation. The distal specimen was used to measure removal torque, and the medial specimens were used for histomorphometric analysis. After implant placement, the periosteum and fascia were sutured with resorbable suture material (Vicryl; Ethicon, Somerville, NJ) and the skin with silk suture. To prevent infection, daily intramuscular injections of cefazolin (250 mg; Yuhan) were given for 1 week.

Removal Torque Measurement

All animals survived the experimental period without incident and, after 6 weeks of healing, all rabbits were sacrificed by intravenous injection of air into the rabbit's ear. The fascia and periosteum were removed, and the distal implant was exposed. The removal torque force was measured with a torque strain gauge (Tohnichi, Tokyo, Japan) (Fig 3) that could measure force to a maximum of 58.8 Ncm. After the removal torque test, cross sections of the specimens were made to confirm that the bone cortex had not been penetrated by the implants.

Preparation and Observation of Tissue Specimens

For preparation of the tissue specimens, the rabbit tibiae were removed, fixed with 70% alcohol so that deformation of the tissue specimens might be minimized, and cut along the long axis of the implant. Microtomography was performed with a Skyscan 1072 x-ray microtomograph (Skyscan, Antwerp, Belgium) before the implants were embedded in resin. After the microtomographic analysis, the implants were preserved and dyed in a villanueva bone stain solution for 1 week. They were then dehydrated in 70%, 90%, and 95% alcohols (once each) and in a 100% alcohol (4 times) for 12 hours and then embedded in methylmethacrylate resin and left under thermoregulated vacuum at 37°C for 40 days. After the slices had hardened, they were cut along the long axis of the implant successively to a thickness of 200 μm by means of a low-speed diamond wheel saw (Maruto, Tokyo, Japan), then ground to a thickness of 30 μm through the Hard Tissue Grinding System (Maruto).

Histomorphometric Analysis

Computer-based histomorphometric analysis was carried out under a light microscope (Olympus BX50, Olympus, Tokyo, Japan) equipped with a charge-coupled device (CCD) camera (Samsung Aerospace, Seoul, Korea) connected to a computer. This system enabled the observer to perform histomorphometric quantifications "directly in the eyepiece of the microscope," using a 10× objective and a zoom of 2.5×. The histomorphometric investigations included measurement of bone-to-implant contact (BIC) and bone volume at every thread (on both the anterior and posterior sides of the implant in the tibia; ie, all threads were measured on the ground sections). In brief, bony contact measurements involved first outlining the entire thread length, and then outlining the metal-bone contacting lengths. By dividing the latter by the former, percentages of bone-to-metal contacts resulted. Bone volume was measured by outlining the total area bounded by the threads, measuring the total area occupied by bone within this region, and dividing the latter area by the former area to express it as percentage of bone volume in the thread (Fig 4).

Morphometric Analysis of the Microtomograms

The possibility of using x-ray microtomography for noninvasive evaluation of the bone-implant interface was suggested by Sennerby and associates.[24] The microtomography was performed with a Skyscan 1072 x-ray microtomograph; this system consisted of a sealed x-ray tube, 20 to 80 kV/100 μA, an 8-μm spot size, and a precision object manipulator with 2 translations and 1 rotation direction. Furthermore, the system included a 12-bit digital cooled CCD camera (1,024 × 1,024 pixels) with fiber optics.

For microtomographic reconstruction, transmission x-ray images were required from 200 rotation views through 180 degrees of rotation (rotation step = 0.9), using a 1.0-mm aluminum filter. The magnification rate for the present study was 15× because of sample size. The microtomographic reconstruction of cross sections was made using a Dual Intel Xeon 1.7 GHz computer under Windows NT. All constructed cross sections contained 1,024 pixels, with a cross

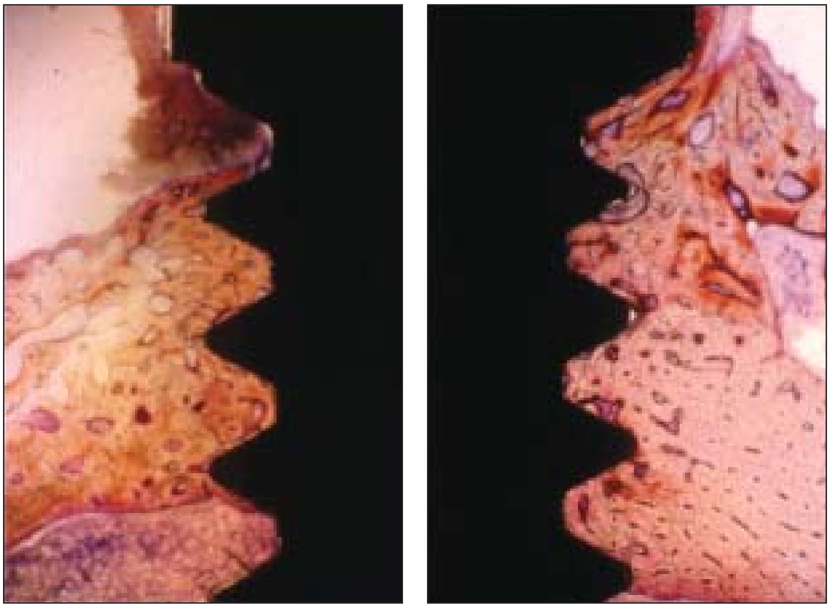

Fig 4 Histologic views of specimens from group 1 *(left)* and group 2 *(right)* (original magnification ×40).

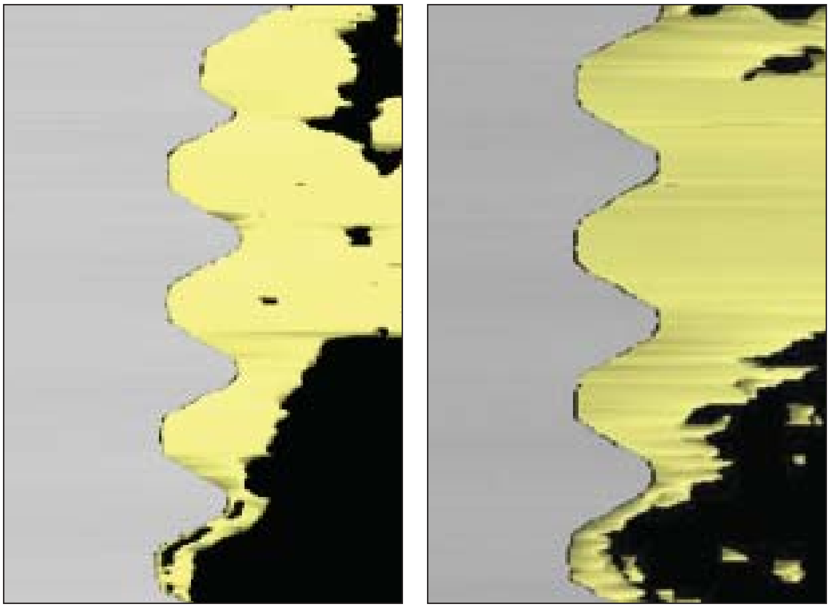

Fig 5 Reconstructed microtomographic views of specimens from group 1 *(left)* and group 2 *(right)* (original magnification ×40).

section pixel size of 15.95 µm and cross section to cross section distances of 15.95 µm.

Three longitudinally tomographic images per specimen reconstructed by 3-dimensional creator program were imported to an image analysis program (ImagePro; Media Cybernetics, Silver Springs, MD) for morphometric analysis. Three images were selected at the center and at locations 2 pixels apart from the center in the cross-sectional view (Fig 5). Morphometric analysis was done as a histomophometric analysis, but only the BIC ratio was measured because the resolution of reconstructed images was determined to be improper to measure the bone volume.

Statistical Analysis

Statistical analysis was performed using SPSS program (version 10.01; SPSS, Chicago, IL). The means and standard deviations (SDs) of all measured categories were calculated, and the Student *t* test was performed to compare the values between 2 groups after verifying the normality of the group by Kolmogorov-Smirnov test. Results were considered significant with $P < .05$.

RESULTS

The mean removal torque measurements were 38.0 Ncm (SD 4.5 Ncm) for group 1 and 44.1 Ncm (SD 3.6

Ncm) for group 2. Group 2 showed a significantly higher mean removal torque force in comparison to group 1 ($P < .05$).

The mean BIC ratios were 59.2% (standard deviation 9.2%) for group 1 and 68.8% (SD 6.2%) for group 2. The BIC ratios for group 2 were significantly higher than those for group 1 ($P < .05$).

The mean bone volumes were 61.9% (SD 8.1%) for group 1 and 71.6% (SD 7.0%) for group 2. The bone volumes in group 2 were significantly higher than those in group 1 ($P < .05$).

The mean BIC ratios measured by microtomogram were 52.4% (SD 7.1%) for group 1 and 59.5% (SD 6.5%) for group 2. Group 2 showed the higher bone to metal contact area which was statistically significant ($P < .05$).

All experimental results are summarized in Tables 1 and 2 and Fig 6.

DISCUSSION

Surface characteristics of implants have an impact on the quality and quantity of bone formed at the interface of implant and tissue.[25] The surface of an implant can be modulated by acid etching, electrolysis, particle-blasting, or coating with crystalline materials such as HA.[26,27]

Rough titanium surfaces are known to be more efficient in terms of osseointegration and bone formation.[27,28] However, it is difficult to compare methods of roughening the surface of implants, since each method (TiO blasting, acid etching, calcium phosphate coating) is carried out using a different approach.[28–30] The incorporation of plasma-sprayed HA coating is one of the most widely used industrial methods for modulation of the implant surface.[31] Extensive in vivo research has shown that new bone formation in the early stages increases when implants are coated with HA,[32–34] so the HA-coated surface has been suggested as a good choice for low-quality bone, where maximum bone formation in the early stages of healing is necessary.[35–37] It is believed that increased bone contact with the implant surface results in more rapid osseointegration as well as increased interfacial strength via early skeletal attachment. The latter has been confirmed by histologic comparison.[37–40] Such increased healing capacity has been attributed to the chemical composition of the HA rather than its microroughness.[41–43]

In their study comparing plasma-sprayed HA coated and machined implant surfaces, Gottlander and colleagues[44] reported that no difference in bone formation was detectable in the early period of loading. However, bone loss around HA-coated implants and bone gain around machined-surface implants was noted after 6 months. A few theories were presented to explain this. First, the high bone contact ratio of HA coating may serve as a cause for bone loss.[45] Second, the abundance of osteoblasts around HA-coated areas promotes bone absorption.[46] Third, disintegrated HA particles serve as activators that promote secretion of interleukin-1 or prostaglandin E_2, which in turn activates osteoclasts.[47]

The HA-coated surface used in the present study maintains a 1-μm thickness and is an improvement over the plasma spray method. The bonding force of metal to HA coatings was reported to be 35 to 70 MPa for IBAD in contrast to 7 MPa for plasma spray methods.[48] Using IBAD method, the problem of separation

Table 1 Mean and SD of Each Measurement

Group	n	Mean	SD
Removal torque (Ncm)			
1	10	38.0	4.54
2	10	44.1	3.57
BIC (%)			
1	10	59.2	9.18
2	10	68.8	6.15
Bone volume (%)			
1	10	61.9	8.08
2	10	71.6	7.01
BIC by microtomogram (%)			
1	10	52.4	7.11
2	10	59.5	6.47

Table 2 Student *t* Test Results

	Levene's test		*t* test for equality of means			
					95% confidence intervals	
	F	*P*	*t*	*P*	Upper	Lower
Removal torque	0.392	.539	−3.336	.004	−9.940	−2.620
BIC	2.283	.148	−2.750	.013	−0.170	−0.023
Bone volume	0.153	.701	−2.883	.010	−0.169	−0.027
BIC by microtomogram	0.000	.999	−2.355	.030	−0.135	−0.008

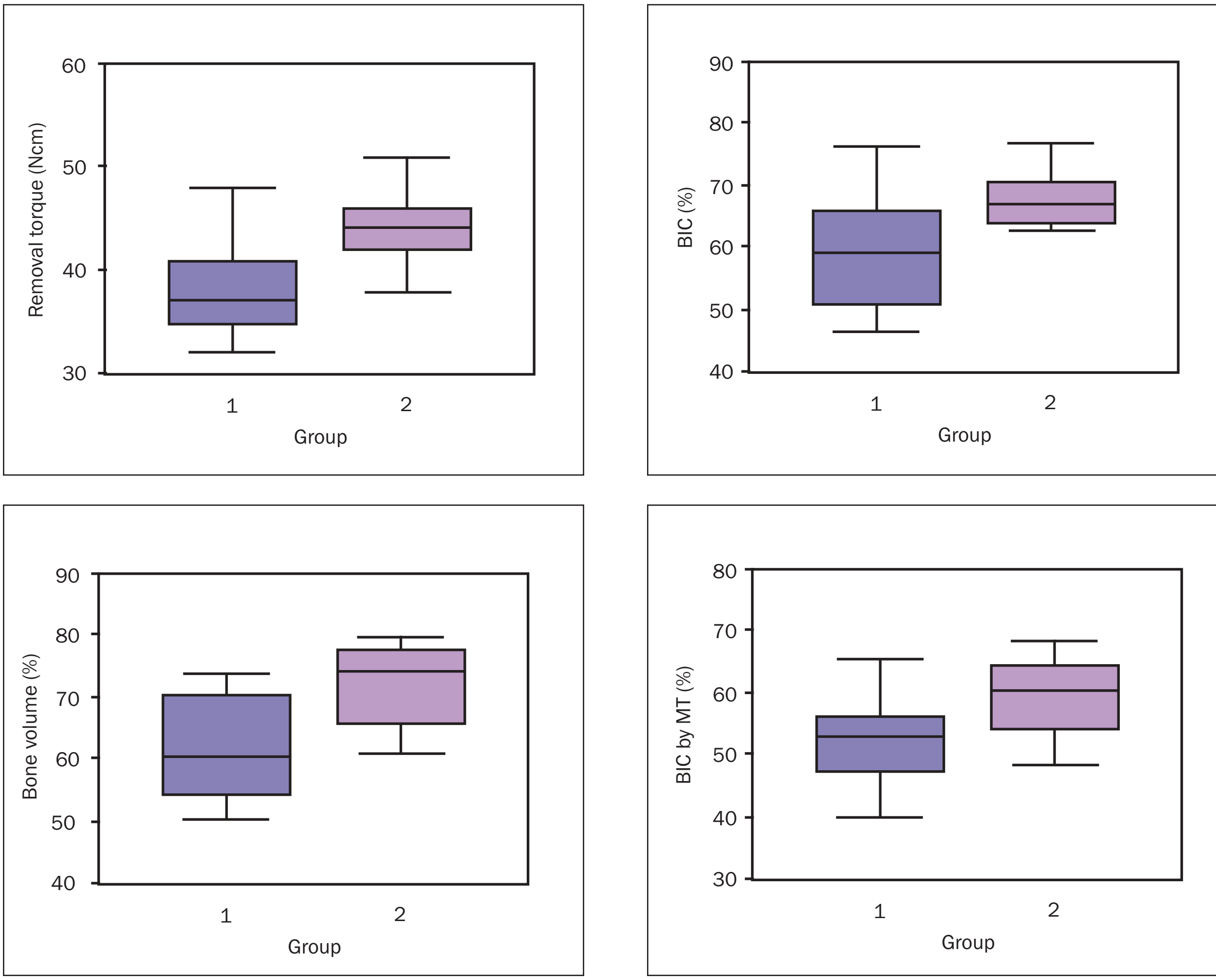

Fig 6 Mean and SD plot of all measurements. MT = microtomography.

or fracture of the coating layers may be precluded, as was found in the previous study.[22] Also, histomorphometric data and removal torque measurements have shown that the HA-coated surface demonstrated comparable or more favorable results than the Al_2O_3-blasted or machined surfaces. Thus, it has been inferred that deposition of an HA coating by means of the IBAD method is an alternative to blasting the surface and assumed that combining the blasted surface with HA deposition can produce more favorable results.

In the present study, the authors compared the blasted surface and the blasted surface with an HA coating deposited using IBAD to evaluate the effect of IBAD of HA on grit-blasted surfaces of similar roughness. Within the scope of this study, IBAD of HA on a grit-blasted implant surface might improve the bone response after implanation.

In analyzing the results of the removal torque test in this study, the risks involved in using hand-driven torque manometers should be noted. Too rapidly applied torques may show false values because of instrument inertia, and too slowly applied torques may also show false values because of bone elasticity.

Primary fixation is one of the most important factors in establishing adequate osseointegration between bone and implant.[49] As discussed earlier, it has been suggested that an HA plasma-spray coating improved the primary fixation by rapid osseointegration.[38–40] Ong and associates compared HA plasma-spray methods with radiofrequency-sputtered calcium phosphate coatings and found that there was no difference in fixation between the 2 methods.[50] Radiofrequency sputtering and IBAD are both methods of thinly coating an implant surface, and there is a possibility that these coatings might have an appropriate dissolution rate. Although there are some controversies about dissolution, several studies suggested that once early osseointegration is achieved, biodegradation of the thin calcium phosphate coatings is not detrimental to bone-implant fixation and does not compromise bone responses to the coated implant surfaces.[50–52] Further study should be performed on the effect of dissolution rates of the various HA coatings.

CONCLUSIONS

1. Within the scope of this study, HA coating using IBAD may improve bone response to a grit-blasted implant surface and have synergistic effects; thus, a thin HA coating may have favorable effects independent of causing surface roughness.
2. Other studies with more specimens are needed.
3. There should be further study on the effects of the dissolution rate of various HA coatings on osseointegration.

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