Regenerated Bone Pattern Around Exposed Implants with Various Designs

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**Purpose:** The design and surface features of dental implants substantially affect the healing and remodeling of adjacent bones. This study aimed to investigate the impact of design and surface on bone regeneration using implants of two different pitches, each with three different surface features. **Materials and Methods:** Custom-manufactured titanium implants (length, 10 mm; diameter, 3.5 mm) were divided along the major axis into two sections: one with 0.6-mm pitch and the other with 0.4-mm pitch. They were processed by turned, blasting and etching, and anodic oxidation surface treatments and implanted into rabbit tibia. The upper 4 mm of the inserted implants was exposed, and bone regeneration was induced around the exposed area using a titanium chamber (height: 4 mm) containing particulate autogenous and bovine bone. After a 12-week healing period, the quantity and quality of bone regeneration around the implants were evaluated. Thirty specimens—10 specimens each from the turned, blasting and etching, and anodic oxidation surface groups with 0.6- and 0.4-mm-pitch sizes—were evaluated by histomorphometric analysis. **Results:** The vertical height and width of regenerated bone around blasting and etching and anodic oxidation surfaces were significantly greater than those around turned implants (P < .05); the vertical heights of regenerated bone around the 0.4-mm-pitch sections of blasting and etching and anodic oxidation surfaces were significantly greater than those around the 0.6-mm-pitch sections (P < .05). Both blasting and etching and anodic oxidation surfaces exhibited significantly greater bone-to-implant contact and bone volume at the implant thread than turned implants (P < .05). However, there was no significant difference between the 0.6- and 0.4-mm-pitch sections. **Conclusion:** The findings of this study indicate that blasting and etching and anodic oxidation surfaces with a 0.4-mm-pitch design result in greater vertical ingrowth of regenerated bone than those with a 0.6-mm-pitch design. Int J Oral Maxillofac Implants 2019;34:61–67. doi: 10.11607/jomi.6715

**Keywords:** anodic oxidation, blasting and etching, bone regeneration, exposed implant, implant pitch, surface features

Availability of an adequate volume of alveolar bone is a key factor for success in implant dentistry. In cases where the volume of alveolar bone is equal to or less than the size of implant, implantation might be impossible or might result in parts of the implant being exposed. Successful implantation, therefore, requires the presence of at least 1 mm or more of supporting bone. Lack of adequate bone volume leads to the mechanical irritation of soft tissue and might also result in impaired stability and poor prognosis of the implant. Therefore, in such cases, bone augmentation is required for successful implant placement. It is possible to place an implant at an ideal site by generating an adequate volume of bone by augmentation with autogenous, allogenous, heterogenous, and synthetic bone grafts. Barrier membrane placement either prior to or in conjunction with implant surgery is one of the augmentation techniques used in case of insufficient bone volume. It allows bone regeneration under the barrier membrane if sufficient space is maintained during the healing period.
Bone tissue to implants has been reported to be very similar to that exhibited by native bone tissue. The design and surface characteristics of implants affect bone regeneration. Surface characteristics of implants, including the quality of material and implant shape, affect cellular activities and interactions among bone tissues. The roughness of surface of implants plays an important role in osseointegration. Specifically, implants with rough surfaces have a high bone-to-implant contact (BIC) ratio. Anodic oxidation and blasting and etching are two of the most widely utilized methods for implant surface treatment. In a study involving beagles, surfaces processed by sand-blasting and acid etching were reported to exhibit a greater BIC ratio than smooth surfaces. Additionally, oxidized surfaces have been shown to interact better with bone tissue than smooth surfaces, because rough surfaces tend to induce more stable interactions with bone tissue than smooth surfaces. Previous studies have revealed that more threaded (lower pitched) implants have a higher BIC percentage. Other research also observed a higher crestal bone loss for implants with a 0.6-mm pitch than those with a 0.5-mm pitch. It is considered that the pitch distance is a significant variable for implant design due to its impact on the surface area. Researchers have concluded that a decrease in pitch size leads to an increased surface area and a more favorable stress distribution of implant design.

However, studies regarding the effect on bone tissue response of implant macrostructure and microstructure in zero wall defects are uncommon. This study aimed to evaluate the influence of various exposed implant designs and surfaces on the pattern of bone remodeling using custom-manufactured turned, blasting and etching, and anodic oxidation surface implants of 0.6- and 0.4-mm-pitch sizes.

**MATERIALS AND METHODS**

**Implant Preparation and Characterization**

Ti6Al4V implants of 10-mm length and 3.5-mm diameter were designed to have a pitch of 0.6 mm on one side of the major axis and 0.4 mm on the other. The implant surfaces were processed by turned, blasting and etching, and anodic oxidation surface treatments. For obtaining the turned surface, the implants were milled with a machine, with no other surface treatments. For obtaining the blasting and etching surface, the implants were manipulated by etching with H2SO4 and HCl after blasting with Al2O3. For obtaining the anodic oxidation surface, the implants were subjected to 300-V direct current passed through an electrolyte solution containing calcium acetate monohydrate and calcium glycerophosphate to form an oxidized membrane in order to confer surface porosity. Ti6Al4V hat-like chambers with an inner diameter of 7.5 mm and height of 4 mm were manufactured for protecting regenerated bone. Additionally, lids and set screws were manufactured to fix the chamber onto the implants (Fig 1). The three different types of implant surfaces were characterized by scanning electron microscopy (SEM; Model S-3000N, Hitachi) at magnifications of ×30, ×500, and ×5,000.

**Animal Experiments**

The animal study protocol was in accordance with the current version of the Korea Law on the Protection of Animals and was approved by the Research Facilities Committee for Laboratory Animal Science, Yonsei University School of Medicine, Seoul, Korea. Veterinary assistance was mandatory throughout the procedures, and all efforts were made to minimize animal suffering during the experimental period. Ten New Zealand rabbits (weight, 3 to 4 kg; age, 15 months) were acclimatized for 2 weeks in the laboratory. They were housed separately and fed standardized feed. Surgery was performed under general anesthesia induced by intramuscular injection of 2 mL/kg ketamine HCl (50 mg/mL; Ketalar, Yuhan) followed by 2% lidocaine HCl (Lidocaine, Yuhan) with epinephrine for local anesthesia. For harvesting autogenous bone, a 5-cm incision was made on the cranium at the sagittal suture, and periosteal flaps were formed. Using a trephine bur (diameter, 6 mm) and a chisel, round sections of cortical bone were excised from either side of the sagittal suture. The tibia was exposed by forming flaps of the fascia and periosteum. Implants were then placed on the anterior medial side of the tibia using 1.5- and 2.8-mm twist drills under saline irrigation; the upper 4 mm of the implants was left exposed. Four implants were randomly chosen from among the three surface types, and each rabbit was implanted with a total of four implants on the left and right tibia (Fig 2). Bone was decorticated around...
the implants using a fissure bur. The titanium chambers were placed on the exposed implants and fixed with set screws. The autogenous bone harvested from the cranium was ground using a bone-miller and mixed with bovine bone (Biocera, Oscotec). The mixture was inserted and condensed into a 2-mm gap between the implant and the chamber. For complete sealing, the grafted bone was covered by a lid screw inserted into the implant. Two implants were placed in the tibia, with a distance of more than 4 mm being maintained between the chambers for preparation of tissue specimens. After implantation, the incisions were closed using absorbable surgical sutures for the fascia and periosteum and 4/0 vicryl sutures for skin. To prevent infection, the rabbits were administered antibiotics (250 mg; Cefazolin, Yuhan) intramuscularly every day for a week.

**Histologic Preparation and Histomorphometric Analysis**

Eight of the 10 rabbits in this study were sacrificed 12 weeks after implant placement (Fig 3). One of the 10 rabbits died after the first week of implantation, and another presented with an exposed chamber and inflammation in both legs; these two rabbits were excluded from the evaluation. One of the eight included rabbits fractured its left leg; yet, the right leg was saved and used for analysis. The remaining seven rabbits did not exhibit any adverse effects. Overall, 30 specimens—10 specimens each from the turned, blasting and etching, and anodic oxidation surface groups with 0.4-mm and 0.6-mm pitch—were evaluated by histomorphometric analysis.

The tibia was extracted to be fixed in a solution of 5% glutaraldehyde and 4% formaldehyde after the fascia and periosteum were removed. All implant samples were prepared as decalcified specimens, dehydrated in 70%, 90%, 95%, and 100% alcohol in succession, and fixed in methyl methacrylate (Technovit VLC 7200, Kulzer). After trimming, the samples were attached to glass slides using methyl methacrylate and sectioned using the Exakt system (Exakt Apparatebau). The specimens were then filed with sandpaper to a thickness of 50 µm, stained with hematoxylin and eosin, and examined under a light microscope (Olympus BX, Olympus) at magnifications of 1.25× and 40×. The images were scanned and digitally measured using image analysis software (Kappa Image base, Kappa Opto-electronics).

Regenerated bones were quantitatively and qualitatively evaluated in order to determine the efficacies of the two types of pitch design and three types of surface features. Quantitative evaluation was performed by measurement of vertical height and width of every surface type of implant at both pitch sizes. Quality of bone regeneration was evaluated by measurement of BIC and bone volume of every surface type of implant for both pitch sizes. Vertical height and width of regenerated bone tissue were measured at a distance of 4 mm from the top of the implant. BIC and bone volume were measured inside the implant valley in regenerated bone tissue (Fig 4).
The data were statistically analyzed using the SPSS software, and the mean value and standard deviation were calculated for each parameter. Comparison of quantitative and qualitative parameters among different types of implant surfaces was performed by analysis of variance, with a 95% significance level, and hypotheses were tested by the Bonferroni test. Comparison of outcomes between the two pitch sizes was performed using the paired t test, with a 95% significance level.

RESULTS

Implant Surface Analysis
The findings of SEM revealed three distinct implant surface characteristics (Fig 5). While the turned surfaces, observed at low and high magnifications (30×, 500×, and 5,000×), exhibited smooth faces, blasting and etching surfaces exhibited rough and irregular patterns produced by the blasting and etching processes. The anodic oxidation surfaces were characterized by the presence of several pores at low magnification and 1- to 20-µm pores at high magnification.

Quantitative Evaluation of Bone Regeneration
Quantitative evaluation of bone regeneration was performed by measurement of vertical height and width of regenerated bones (Fig 6). The mean vertical heights of regenerated bone around the 0.6-mm-pitch sections of turned, blasting and etching, and anodic oxidation surfaces were 0.40 ± 0.09, 0.73 ± 0.18, and 0.68 ± 0.17 mm, respectively (Fig 7); the corresponding values for the 0.4-mm-pitch sections were 0.44 ± 0.08, 1.10 ± 0.43, and 1.08 ± 0.35 mm, respectively. The mean vertical heights of regenerated bone around blasting and etching and anodic oxidation surfaces were significantly greater than that around turned implants. The mean vertical heights of regenerated bone around the 0.4-mm-pitch sections of blasting

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and etching and anodic oxidation surfaces were significantly greater than those around the 0.6-mm-pitch sections. However, there was no significant difference in vertical height between the two pitch designs in turned implants.

The mean widths of regenerated bone around the 0.6-mm-pitch sections of turned, blasting and etching, and anodic oxidation surfaces were 0.42 ± 0.14, 0.62 ± 0.15, and 0.64 ± 0.19 mm, respectively, while the corresponding values for the 0.4-mm-pitch sections were 0.48 ± 0.09, 0.71 ± 0.14, and 0.76 ± 0.11 mm, respectively. Although the mean width of regenerated bone around turned implants was significantly lower than those around blasting and etching and anodic oxidation surfaces, there were no significant differences in bone width between the two pitch sizes in any of the three surface types.

Qualitative Evaluation of Bone Regeneration

Qualitative evaluation was performed by measurement of BIC and volume of regenerated bone (Fig 8). The mean values of BIC at the 0.6-mm-pitch sections of turned, blasting and etching, and anodic oxidation surfaces were 35.04% ± 15.17%, 69.64% ± 12.45%, and 63.92% ± 14.68%, respectively (Fig 9), while the corresponding values at the 0.4-mm-pitch sections were 46.52% ± 9.62%, 70.71% ± 4.10%, and 68.97% ± 16.82%, respectively.

The mean volumes of regenerated bone at the 0.6-mm-pitch sections of turned, blasting and etching, and anodic oxidation surfaces were 57.42% ± 7.77%, 73.65% ± 7.47%, and 71.20% ± 5.52%, respectively, while the corresponding values at the 0.4-mm-pitch sections were 59.02% ± 7.86%, 74.20% ± 10.14%, and 76.04% ± 4.97%, respectively.

DISCUSSION

In the present study, the presence of a regeneration pattern around exposed implants might be perceived as characteristics. Also, the present histomorphometric findings on regeneration bone patterns according to the pitch and surface type confer great significance to this study.

The present findings revealed that both blasting and etching and anodic oxidation surfaces exhibited better outcomes in terms of vertical height, width, BIC, and bone volume at the implant thread than turned surfaces. Implant surface and design are important factors that affect bone healing in guided bone regeneration. Osseointegration at implant sites occurs in two ways—bone growth from implant-adjacent bone tissue and bone formation on the implant surface by osteoblasts. Implants with turned surfaces tend to undergo osseointegration by appositional bone growth, while those with rough surfaces exhibit bone formation on the surface by osteoblasts as well as appositional bone growth.11 Additionally, implants with a rough surface and large area provide improved biomechanical bone-implant bonding, and irregular implant surfaces can influence nearby osteoblasts to accelerate cell differentiation.12 The concentrations of bone

The mean values of BIC and volume of regenerated bone at both 0.6-mm and 0.4-mm pitches of turned implants differed significantly from those of blasting and etching and anodic oxidation surfaces. There was no significant difference in BIC or volume of regenerated bone between the 0.4- and 0.6-mm-pitch sections, regardless of surface type.
growth–related factors such as osteocalcin tend to be relatively high on rough implant surfaces.13 Several studies on evaluation of implant surfaces have employed blasting and etching and anodic oxidation surface treatments as representative methods. In blasting and etching treatment, implants are given a rough surface by spraying an oxidized aluminum abrasive, and the roughness is adjusted by acid etching. A representative method of the blasting process after acid etching is sandblasted large-grit acid etching (SLA); SLA treatment of implant surfaces has been reported to improve implant osseointegration and shorten the duration of bone healing, thus enabling prosthesis loading just 6 weeks after implant placement.14 The anodic oxidation method involves oxidation of the titanium surface of the anode by incremental placement of oxide layers by conduction of electricity through electrolytes. In the present study, calcium acetate monohydrate and calcium glycerophosphate were used as electrolytes for anodic oxidation. According to the histologic findings of a previous study, oxidized surfaces exhibit better interactions with bone tissue than smooth surfaces10; this result is attributable to the faster stabilization of oxidation implants compared with that of smooth-surfaced implants in areas of bone defect. Specifically, bone formation around oxidation implants is accelerated by the greater stability between bone matrix and implant surface.15 Similarly, in the present study, blasting and etching and anodic oxidation surfaces exhibited better outcomes than turned surfaces in terms of vertical height, width, BIC, and bone volume on regeneration patterns.

In the present study, the 0.4-mm-pitch sections of blasting and etching and anodic oxidation surfaces exhibited greater vertical height of regenerated bone than did the corresponding 0.6-mm-pitch sections. Relative to the 0.6-mm design, the 0.4-mm-pitch design is thought to be more suitable for bone ingrowth by a trabecular network of woven bone. The healing pattern of bone tissue depends on the size of the bone defect. When the size of the bone defect is ≤ 0.2 mm, the area is regenerated into lamellar bone. At sizes of 0.2 to 0.5 mm, a woven bone connecting the trabecular network is initially formed in the area of defect, and the trabecular area is finally replaced by lamellar bone. Bone defects larger than 0.5 mm do not exhibit direct bone formation; instead, they exhibit integration of connective tissues.16

In the absence of a barrier, movement of rabbits might disturb bone regeneration on the tibia. To prevent such a scenario, a hat-like chamber for bone regeneration was designed and applied in the present study. Previous studies have reported that bone

Fig 8  Histologic evaluation of quality of bone regeneration (×40). Bone-to-implant contact and bone volume were measured at the inner side of the implant valley. Implants with (b, e) blasting and etching and (c, f) anodic oxidation surfaces exhibited greater bone-to-implant contact and volume of regenerated bone tissue than those with (a, d) turned surfaces.

Fig 9 Bone-to-implant contact and bone volume at implant thread. Bone-to-implant contact and regenerated bone volume at implant thread were compared among the three types of implants (turned, blasting and etching, and anodic oxidation surfaces) and two pitch sizes (0.6 and 0.4 mm).
growth chambers are useful for evaluation of bone regeneration.\(^1\)\(^7\) In the present study, autogenous and bovine bone tissues were used for successful bone regeneration. Although autogenous bone is the gold standard for grafting, bovine bone is more commonly used because of the limitations associated with the retrieval of autogenous bone. As a scaffold, bovine bone exhibits osteoinductive properties, which induce successful bone tissue formation.\(^1\)\(^8\) Using a combination of autogenous and bovine bone for bone regeneration increases the chances of successful outcome.\(^1\)\(^9\) In case of autogenous bone, bone growth factors stimulate bone formation.

Bone regeneration of various designs around exposed implants, which are frequently encountered by clinicians, demonstrated meaningful patterns. Further research regarding the effects of implant design and surface on the long-term stability of regenerated bone is required.

**CONCLUSIONS**

In bone regeneration, the response of implant-adja-
cent bone tissue differs according to the surface and pitch of the implant. The present findings indicate that blasting and etching and anodic oxidation surfaces are more effective for bone regeneration than turned surfaces. Additionally, the 0.4-mm-pitch design of blasting and etching and anodic oxidation surfaces is more effective for vertical bone regeneration than the 0.6-mm-pitch design.

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