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Effect of XPEED® on Ti implants with deep threads

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Abstract. Calcium-incorporated titanium (Ti) recently reported a large degree of effectiveness in many *in vitro* and *in vivo* studies. The implants with the deeper thread provide the higher surface area and will have an advantage in soft bone. We used the Ti implants with deep threads and investigated osseintegration of the implants with resorbable blast media (RBM) surfaces produced by grit-blasting or XPEED® surfaces by coating of the nanostrucutred calcium.

The Ti implants with deep threads had a thread diameter of 4.0 mm, a length of 5.0 mm and a thread depth of 1.0 mm. The Ti implants with calcium-incorporated surfaces (XPEED® surfaces) were hydrothermally prepared from the Ti implants with RBM surfaces in alkaline calcium containing solution. The surface characteristics were evaluated by using scanning electron microscope (SEM) and surface roughness measuring system. Thirty-implants with RBM surfaces and thirty-implants with XPEED® surfaces were randomly placed in the proximal tibiae and in the femoral condyles of ten New Zealand White rabbits. The osseointegration was evaluated by removal torque test in the proximal tibiae and histomorphometric analysis in the femoral condyles.

The Ti implants with XPEED® surfaces showed a similar surface morphology and surface roughness to those of the Ti implants with RBM surfaces. The mean removal torque of the Ti implants with XPEED® surfaces was higher than the Ti implants with RBM surfaces ($p < 0.05$). The percentage of bone-to-implant contact (BIC %) were increased for the Ti implants with XPEED® surfaces compared with the Ti implants with RBM surfaces ($p < 0.05$).

The Ti implants with XPEED® surfaces significantly enhanced the removal torque and the BIC %. The Ti implants with XPEED® surfaces may be shorten healing time of bone by improving osseointegration of Ti implants with deep threads.

Introduction

Osseointegration is related to the bone contact between the implant and the surrounding bone. The bonding of bone contact with implant is affected by many factors such as surgical technique, host bed, implant design, implant surface, material biocompatibility and loading conditions [1].

With the surface roughness and topography, the surface chemistry plays an important role for osseointegration. Titanium (Ti) and Ti alloys are bioinert surfaces and are not able to directly bond with bone. One of the methods of increasing surface reactivity is coating the Ti surface with layers of calcium phosphate. Plasma-sprayed HA coating is a widely-used method. The studies reported that the dental implants with the HA coating enhance osseointegration as compared to noncoated dental implants [2,3]. Another study reported that the survival rate of the dental implant with or without the HA coating is similar [4] or decreases in the dental implants with the HA coating [5]. Plasma-sprayed

HA coating produces the bioactive implant surface like these studies but has several disadvantages. The plasma coating is closely attached to the bone tissue and is delaminated from the surface titanium implant [6,7]. Another method of increasing surface reactivity is to coat the nanostructured calcium into the Ti surface. The nanostructured calcium coating recently reported a large degree of effectiveness in many *in vitro* and *in vivo* studies. The *in vitro* studies have reported that surface modification from the use of calcium ions increased the growth of osteoblastic cells and promoted the precipitation of apatite on the Ti surfaces in simulated body fluid [8,9,10]. Several *in vivo* studies have reported that incorporating calcium into Ti implants by hydrothermal treatment stimulated osseointegration by increasing BIC % more than in untreated Ti implants in rabbit models [11,12]. It was reported that the surface roughness only was modified at the nano-scale level but not the micron-scale level after calcium incorporation by hydrothermal modification [11].

Thread geometry is an important factor that gets an effect on implant initial stability and osseointegration. Thread geometry such as thread shape, face angle, and thread pitch contributes the distribution of stresses around the implant. Deeper thread depth has an advantage in area of softer bone because of the wider surface area in contact with surrounding bone [13].

Although several studies have documented osseointegration on Ti implants with incorporated calcium, few have investigated the effects of calcium ions on Ti implants with deep threads. We used the Ti implants with deep threads and investigated osseointegration of the implants with resorbable blast media (RBM) surfaces produced by grit-blasting or XPEED® surfaces by coating of the nanostrucutred calcium.

Materials and Methods

Implant design. The Ti implants with deep threads had a thread diameter of 4.0 mm, a length of 5.0 mm and a thread depth of 1.0 mm. The calcium-incorporated Ti implants, that is, the Ti implants with XPEED® surfaces, were prepared by hydrothermal reaction in the same manner as previous studies [11,14]. Briefly, the Ti implants were hydrothermally treated in a mixed solution containing 2 mM CaO and 0.2 M NaOH at 180°C for 2 hrs. All implants used this study were sterilized by γ-irradiation.

Surface characterization. The morphology of the Ti implant surface was observed by scanning electron microscope equipped with energy dispersive X-spectroscope (SEM/EDS, S-4800, Hitachi, Tokyo, Japan). The surface roughness was evaluated by a surface roughness measuring system (Form Talysurf Series 2, Taylor Hobson, Leicester, England).

Animals and surgical procedure. The animal experiment was approved by the Institutional Animal Care and Use Committee of Yeungnam National University Hospital, Daegu, Korea. Ten adult male New Zealand White Rabbits weighing 3.5 - 4kg were used. The incision for the surgical sites was made on the medial surface of the distal femur and the medial surface of the proximal tibiae from the skin to the periosteum. The osteotomy was performed according to the recommended surgical protocol supplied by the manufacturer. The holes for implant implantation were drilled in sequential order. A set of three control implants (implants with RBM surfaces) and a set of three experimental implants (implants with XPEED® surfaces) were randomly placed in the right legs and left legs (two implants in the tibia and one implant in the femur) The implants with RBM surfaces (n = 30) and the implants with XPEED® surfaces (n = 30) were implanted with the recommended torque. All implants were inserted up to the bone cortex. The surgical site was then sutured with Vicryl (Ethicon, Somerville, NJ, USA), and the antibiotic Baytril (Bayer, Korea) and analgesic Nobin (Bayer, Korea) were injected intramuscularly to minimize infection and pain.

Removal torque tests. After 4 weeks, to evaluate implant stability, removal torque tests were performed in the proximal tibia bed with the implants. After the incision of the surgical site, the removal torque was measured by using a digital torque meter (Mark-10, New York, USA) positioned in the same direction of the implant axis with constant speed.

Histomorphometric evaluation. After 4 weeks, tissues containing implants from the femoral condyles were harvested and fixed in 70% ethanol. The tissue was dehydrated sequentially in ethanol, and then embedded in methyl methacrylate resin. The sections of 20 ㎛ thickness were stained with Villanueva staining and were photographed with a trinocular microscope (CX31, Olympus, Tokyo, Japan). BIC % was measured as a percentage of the length of mineralized bone contacting the implant surface directly. The percentage of bone-to-implant contact (BIC %) was measured with an image analysis program (Analysis TS Auto, Olympus, Tokyo, Japan).

Statistical analysis. Data were analyzed by a Student *t*-test using the SPSS 11.0 statistical system. Values of *p* were statistically significant at < 0.05.

Result and Discussion

The surface morphology of the Ti implants with RBM surfaces showed the micro-rough surface topography and the irregular indentation (Figure 1). By incorporating calcium ions, the Ti implants with XPEED® surfaces were observed to have a similar surface morphology to that of the Ti implants with RBM surfaces at lower magnifications (x 1,000, x 3,000). At the higher magnification (x 30,000), the Ti implants with XPEED® surfaces were observed to have a surface nanostructure with a regular shape.

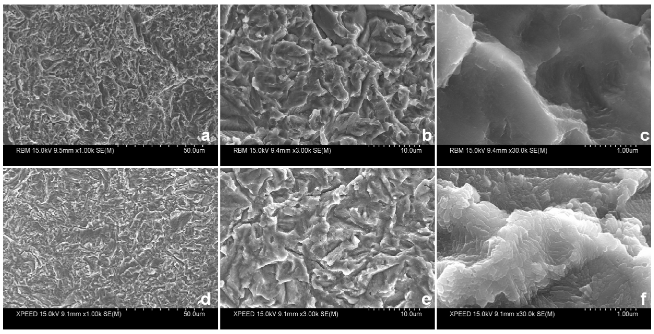

Figure 1. Scanning electron microscope of the Ti implants with RBM surfaces (a, b, c) and the Ti implants with XPEED® surfaces (d, e, f) at magnifications of × 1000 (a, d), × 3000 (b, e), and × 30,000 (c, f).

The average surface roughness (R_a) of the Ti implants with RBM surfaces and XPEED® surfaces was similar (Table 1).

Table 1. Surface roughness parameters of the Ti implants with RBM surfaces and XPEED® surfaces

Surface treatment	R_a (㎛)	R_q (㎛)	R_t (㎛)	R_{zDIN} (㎛)
RBM	1.56±0.08	2.11±0.13	18.53±1.56	12.55±0.32
XPEED	1.63±0.22	2.16±0.30	15.76±0.29	12.46±0.55

R_a, the arithmetic average of the absolute height values of all points of the profile; R_q, the root mean square of the values of all points of the profile; R_t, the maximum peak-to-valley height of the entire measurement trace; R_{zDIN}, the arithmetic average of the maximum peak to valley height of the roughness values of five consecutive sampling sections over the filtered profile.

The mean removal torque of the Ti implants with XPEED® surfaces was 28.9±9.7Ncm and that of the Ti implants with RBM surfaces was 20.5±7.8Ncm (Figure 2). The mean removal torque of the Ti implants with XPEED® surfaces was even higher than the Ti implants with RBM surfaces ($p < 0.05$).

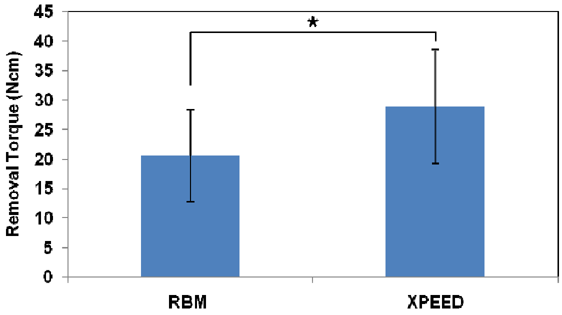

Figure 2. The removal torque value of the Ti implants with RBM surfaces and the Ti implants with XPEED® surfaces 4 weeks after implantation in rabbit tibiae (*$p<0.05$).

At 4 weeks after implantation, we showed to be form bones until inside deep threads (Figure 3). All implants in the implantation site were observed to have no histological inflammation at the bone-implant boundary. The mean BIC % was 53.2±7.7% for the Ti implants with RBM surfaces and 73.4%±8.7% for the Ti implants with XPEED® surfaces (Figure 4). The BIC % of the Ti implants with XPEED® surfaces was significantly enhanced compared to the Ti implants with RBM surfaces ($p < 0.05$). This result is consistent with previous report showing that the nano-structured calcium-incorporated surfaces enhance ossteointegration [12,13]. These results suggests that XPEED® surfaces improve the osseointegration of Ti implants with deep threads.

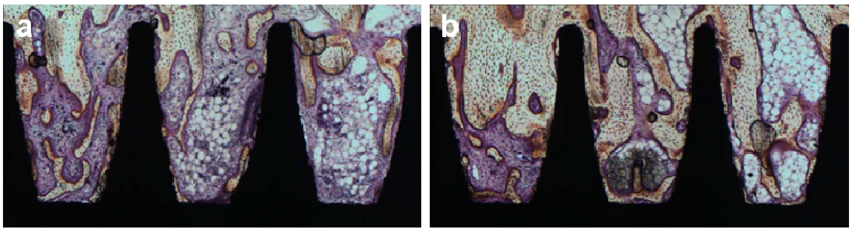

Figure 3. Histological sections of the Ti implants with RBM surfaces (a) and the Ti implants with XPEED® surfaces (b) 4 weeks after implantation in rabbit femurs. Magnification of x 100 (stained with Villaneueva stain) (*$p<0.05$).

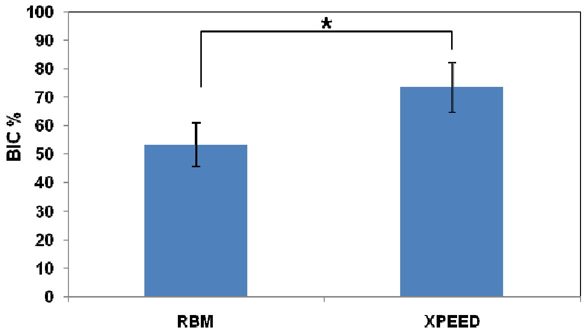

Figure 4. Mean percentage of the bone-to-implant contact (BIC %) in first three threads of Ti implants at 4 weeks after implantation in rabbit femurs.

Summary

We found that the Ti implants with XPEED® surfaces showed a similar surface morphology and surface roughness to those of the Ti implants with RBM surfaces. The Ti implants with XPEED® surfaces significantly enhanced the removal torque and the BIC %. The Ti implants with XPEED® surfaces may be shorten healing time of bone by improving osseointegration of Ti implants with deep threads.

Acknowledgements

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