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Evaluation of Osseointegration Levels of Different Surface Feature Titanium Implants Installed Simultaneously with Graft: An Animal Study

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Objective: This study aims to evaluate the bone-implant osseointegration following the healing process of machined, reabsorbable blast media (RBM) and sandblasted large-grit acid-etched (SLA) surface titanium implants placed simultaneously using graft material in rat tibias.

Materials and Methods: The study involved 30 Sprague-Dawley rats that were divided into three groups: machined surface (MS) (n=10), RBM surface (n=10), and SLA surface (n=10). The titanium implants were placed into prepared bone sockets with the graft material, and the rats were euthanized after a four-week experimental period. The implants and surrounding bone tissue were collected for reverse torque analysis (Newton's- centimeters).

Results: The biomechanical bone–implant contact rate was significantly higher in SLA- and RBM-surfaced implants compared with machined-surfaced implants ($p<0.05$). However, no statistically significant difference in bone–implant contact rate was observed between the SLA and RBM surface groups ($p>0.05$).

Conclusion: The application of graft material may be more effective in implants with SLA and RBM surfaces, as per the biomechanical parameters.

Key Words: *Biomechanics, graft, osseointegration, implant, surface*

Greftle Eş Zamanlı Yerleştirilen Farklı Yüzey Özellikli Titanyum İmplantların Osseointegrasyon Düzeylerinin Değerlendirilmesi: Deney Hayvan Çalışması

Amaç: Bu çalışmanın amacı, sıçan tibialarına greft materyali kullanılarak eş zamanlı olarak yerleştirilen işlenmiş, resorbable blast media (RBM) ve sandblasted large-grit acid-etched (SLA) yüzeyli titanyum implantların iyileşme sürecini takiben kemik-implant osseointegrasyonunu değerlendirmektir.

Gereç ve Yöntem: Çalışmaya işlenmiş (machined) yüzey (MS) (n=10), RBM yüzey (n=10) ve SLA yüzey (n=10) olmak üzere üç gruba ayrılan 30 Sprague-Dawley sıçanı dahil edilmiştir. Titanyum implantlar greft materyali ile birlikte önceden hazırlanmış kemikteki implant soketlerine yerleştirildi ve sıçanlar dört haftalık bir deney süresinden sonra ötenazi edildi. İmplantlar ve çevreleyen kemik dokusu, ters tork analizi (Newton-santimetre) için toplandı.

Bulgular: Biyomekanik kemik-implant temas oranı, SLA ve RBM yüzeyli implantlarda işlenmiş yüzeyli implantlara kıyasla istatistiksel olarak anlamlı derecede daha yüksek bulunmuştur ($p<0.05$). Ancak, SLA ve RBM yüzeyli implantlar arasında kemik-implant temas oranı açısından istatistiksel olarak anlamlı bir fark saptanmamıştır ($p>0.05$).

Sonuç: Biyomekanik parametrelere göre, greft materyali ile birlikte SLA ve RBM yüzeyli implantların kullanılması osseointegrasyon **derecesini arttırabilir.**

Anahtar Kelimeler: *Biyomekanik, greft, osseointegrasyon, implant, yüzey*

Introduction

Dental implant-supported prostheses, which are connected directly to the bone surface without intervening connective tissue, have been a scientifically accepted and frequently used treatment option in complete and partial edentulism (1, 2). However, jawbone defects cause problems in the placement and function of dental implants in the jawbone. In order to overcome these problems, various biomaterials and methods are used in the treatment of jawbone defects (3).

With the rise of aesthetic demands and advances in chairside technology, patients increasingly expect rapid resolution of bone deficiencies. The successful clinical performance of dental implants largely depends on bone-implant osseointegration. Dental implant topography is one of the most important parameters affecting bone-implant osseointegration (4). The categorization of dental implant topography can be done on a scale basis into macro, micro, and nano subgroups (5, 6). The visible shape of an implant defines its macrotopography (7). The microtopography is determined by micro roughness (1-100 μm) (8). Changes in microtopography influence the growth, metabolism, movement, and the production of cytokines and growth factors in osteogenic cells by expanding the surface area (9). It is thought that the nanotopography (1-100 nm) of implants has an effect on a cellular and protein level (10). Implant topography modifications fall into three interrelated categories: physical, mechanical, and chemical (11). Machined, SLA, and RBM are micro level modifications in the physical category. These modifications can enhance the fibrin matrix formation as an osteoconductive scaffold by increasing the surface area of the implants on a micrometer scale (12).

Machined-surface implants, the first generation of dental implants, were commonly used until the 1990s (13). These surfaces exhibit moderate hydrophilicity, influencing blood clot formation and cell attachment, which are important steps in the osseointegration process (14). Although the surfaces of these implants appear smooth to the naked eye, slight grooves and ridges formed during the manufacturing process can be detected by scanning electron microscopy (SEM). These slight surface imperfections, with an average roughness of 0.96 µm, effectively support the attachment and deposition of osteogenic cells into the bone matrix. Surfaces roughened to 1–1.5 µm generally achieve stronger fixation (13). Although machined surfaces have been employed on dental implants for many years with favorable clinical outcomes, various surface modification techniques, such as SLA and RBM, have been developed to further enhance surface roughness, thereby improving bone–implant contact and fixation compared to earlier machined designs (13-15).

SLA (Sandblasted, Large-grit, Acid-etched) implant surface modification technique involves the use of coarse abrasive particles (ranging from 250 to 500 µm) to alter the macrogeometry of titanium implants, followed by acid etching to generate micro-scale surface irregularities that enhance osseointegration (13). The RBM (Resorbable Blast Media) approach employs a comparable dual-step process—mechanical abrasion and chemical etching—to optimize surface topography. A key distinction lies in the type of abrasive media utilized: SLA relies on non-resorbable particles such as alumina, whereas RBM incorporates bioresorbable materials like hydroxyapatite or calcium phosphate. The use of resorbable particles in RBM reduces the likelihood of residual debris and may facilitate more efficient bone-implant osseointegration (15).

In clinical studies in which implant surfaces were evaluated in terms of bone-implant osseointegration, it has been observed that implant surface systems do not have a complete superiority to each other (16, 17). It can be suggested that the bone surface may have an effect on the implant osseointegration in implants placed simultaneously with graft material.

Xenogenic grafts, particularly those derived from deproteinized bone, are associated with a comparatively lower incidence of postoperative infection and present a more economical alternative to synthetic alloplastic materials (18-20). Additionally, they are more readily accessible than autologous grafts, which require harvesting from the patient (18, 19). Deproteinized bone substitutes exhibit compositional and structural characteristics akin to native human bone, including comparable calcium-to-phosphorus ratios and surface morphology (18, 19). Among the xenografts employed in guided bone regeneration (GBR), bovine-derived deproteinized bone has gained prominence in clinical settings due to its favorable biological behavior. These grafts support bone regeneration through osteoconduction and demonstrate a gradual resorption profile, contributing to the long-term maintenance of grafted volume (18).

This research intended to examine the osseointegration of titanium implants with turned, sandblasted, etched and roughened surfaces, which were implanted in rat tibias along with graft material, post-healing. The hypothesis of this study is that different implant surface treatments may affect the osseointegration of implants applied simultaneously with the graft material.

Materials and Methods

Research and Publication Ethics: The study was approved by the Fırat University Animal Experiments Ethics Committee (approval no. 2021/02) and was conducted in accordance with the applicable national legislation and institutional guidelines for the care and use of laboratory animals.

Animals and Study Design: All experimental and surgical processes were conducted at the Experimental Research Center of Firat University, in Elazığ, Türkiye. Thirty healthy adult female Sprague-Dawley rats, aged 1 to 1.5 years, were included in the study. The rats' average body weight ranged from 250 to 300 g at the start of the experimental protocol. The rats were housed in a temperature-controlled environment using plastic cages. The rats were allowed to eat and drink freely and were exposed to a 12-hour light-dark cycle throughout the study. The rats were randomly allocated into three groups, each with ten rats, ensuring similar mean weights across all groups. Experimental groups: The implant groups were formed from machined surface (n=10), resorbable blast media surface (n=10) and sandblasted and acid-etched surface (n=10) implant groups.

Surgical Procedures: No additional nutritional supplements were administered before, during or after the experiment and no state of deprivation was applied. All surgical procedures were carried out in compliance with the principles of maintaining a sterile environment and preventing the growth of microorganisms. All subjects were administered 35 mg/kg of ketamine hydrochloride and 5 mg/kg of xylazine intramuscularly for anesthesia. After general anesthesia, the surgical area was washed with povidone-iodine and shaved. After the surgical area was cleaned with povidone-iodine, it was covered with sterile drapes that exposed the surgical area. The crest was incised to access the metaphyseal part of the right tibia. The skin flap was lifted and the periosteum was dissected. Each tibia was made the bone sockets that measured 4 mm in diameter and 5 mm in length. Bone xenogenic grafts (Bio-Oss using small particles 0.25-1 mm) were inserted into the sockets, and 2.5 mm diameter and 4 mm length titanium implants (TiAl6V4, Implance Dental Implant Systems, AGS Medikal Corporation, Istanbul, Turkey) were placed into the xenogenic grafts simultaneously. After these procedures, the subjects' skin and soft tissues were returned to their initial positions and closed using 4-0 prolene sutures. At the end of the 4-week recovery period, the subjects were sacrificed. Bone-implant fusion analyses of the obtained samples were performed using a biomechanical reverse torque device. The data were obtained as force. Improperly placed implants were excluded from the study.

Biomechanical Analysis: No fatal or nonfatal complication was encountered during the study. After euthanasia, right tibial bone samples were removed, and unsuitable samples were excluded from the study. Removal torque tests were performed to assess implant stability. The remaining samples were rigidly immobilized. Reverse torque testing was performed using a digital torque meter (Mark-10 Corporation, New York, NY, USA). Counterclockwise rotation was applied, and all maximum torque values measured when the reverse rotation was initiated were recorded. This study evaluated machined, SLA, and RBM surface implants. Four weeks after implantation, removal torque values were measured and compared between the samples placed in the tibia.

Power Analysis: The number of animals required for the experiments was determined using a power analysis. Calculations were performed assuming an 8% deviation, a type I error rate (α) of 0.05, and a statistical power of 0.80. Based on these parameters, a minimum of seven animals per group was considered sufficient. To account for potential losses during the experimental period, the sample size was increased to ten animals per group.

Statistical Analysis: IBM SPSS Statistics 22 software was utilized to perform statistical analysis on the data in the study. The normality of the data distribution was assessed using the Shapiro–Wilk test. Since the data were normally distributed, a one-way analysis of variance (ANOVA) was conducted to evaluate differences among the groups. As homogeneity of variances was not met, Games–Howell post hoc test was used for pairwise comparisons. Significance was evaluated at the $p<0.05$ level.

Results

After excluding four implants due to improper positioning (one from the machined surface group, two from the RBM group, and one from the SLA group), the remaining 26 implants were evaluated at the end of the fourth week, and the highest extraction (removal) torque values were recorded at this time point. Of these values, four (one from the machined surface group, one from the RBM group, and two from the SLA group) were excluded from the analysis as outliers to improve statistical reliability and ensure a more objective evaluation of the data; the remaining 22 values were included in the statistical analysis. The normality of the obtained data was assessed using the Shapiro–Wilk test, and the results indicated that the data were normally distributed. Accordingly, a one-way analysis of variance (ANOVA) was performed to determine whether there were statistically significant differences among the groups. Since the variances were not homogeneous, the Games–Howell post hoc test was used for pairwise comparisons. The analyses revealed a statistically significant difference among the groups ($p<0.05$). According to the post hoc results, the mean value of the machined surfaces (3.90 N/cm) group was significantly lower than those of the RBM (6.25 N/cm) and SLA (8.88 N/cm) groups ($p<0.05$). However, no statistically significant difference was found between the RBM and SLA groups ($p>0.05$, Table 1).

Table 1. Biomechanical BIC (N/cm) parameters of the groups according the reverse torque analysis.

Groups	N	Mean (N/cm)	Standard Deviation	*p*
Machined	8	3.90	0.507	
RBM^{a1}	7	6.25	1.632	0.002
SLA^{a2}	7	8.88	3.651	

Comparison of removal torque values (N/cm) among machined, RBM, and SLA surface implant groups. Data are expressed as mean ± standard deviation. Normality was assessed using the Shapiro–Wilk test. One-way ANOVA revealed a significant difference among groups ($p=0.002$). Pairwise comparisons were performed using the Games–Howell post hoc test. [a]Significantly different compared with the machined surface group ($p<0.05$). a1: 0.019, a2: 0.026.

Discussion

In dental implant treatment, there may not always be enough bone tissue to allow the surgical placement of the implant due to reasons such as; vertical and horizontal bone deficiencies, sinus droop, and non-ideal conditions such as low bone mineral density and osteoporosis. Graft materials and implants with the ideal surface properties that can be simultaneously applied with them in order to have successful and early clinical results in patients with bone defects have attracted the attention of researchers (2, 4). In this study, a statistically significant difference was found in the osseointegration values between the MS, SLA and RBM surface dental implants placed simultaneously with the xenogenic graft. The biomechanical bone-implant osseointegration values of the SLA and RBM surface implants were found to be higher than the machined surface implants. When RBM- and SLA-surfaced implants were compared, no statistically significant difference was found in terms of osseointegration values. These results suggest that implant surface preparation methods are not only effective in the interaction of healthy bone tissue with the implant surface, but also in the interaction of graft materials and the implant surface (2, 4). It has been reported in many studies that rough surface implants are more advantageous in bone-implant osseointegration than machined surface implants. Machined surfaces are used as a control group in studies examining implant surface properties (2, 4). Demetoğlu et al. (21) clinically compared RBM and SLA surface implants in their study involving 2005 patients and reported that a significant difference in terms of osseointegration success between the two groups of implants was not detected. In a study evaluating the osseointegration levels of implants with five different surfaces, Dundar et al. (22) placed implants in the femurs of rats and evaluated bone-implant osseointegration with non-decalcified histological examination. In the study, the levels of osseointegration in the SLA and RBM implants and the percentage of contact with bone tissue was examined, and it was stated that the two different surfaces did not have superiority to each other. In their study examining the osseointegration and surface properties of nano, SLA and RBM surface-like target-ion-induced plasma-sputtered surface implants produced with 3D printed, Lee et al. discovered that treating the surface of 3D printed implants can help with the initial deposition of organic matrix and mineralized bone, however the surface comparison of features did not produce any significant results (23). In the present study, consistent with the findings reported in the literature, similar levels of osseointegration were observed in SLA- and RBM-surfaced implants placed simultaneously with graft material. On the other hand, Özcan et al. compared the effects of locally applied ankaferd hemorrhage stopper (ABS) on peri-implant bone healing using implants with three different surfaces; RBM, SLA, and turned surface. It was reported that implants with SLA and RBM surfaces showed higher bone implant osseointegration than implants with turned surfaces and that the surface of SLA implants may be more effective in ABS applications (24). In an experimental histomorphometric study on rabbits by Le Guehennec et al. (4), it has been reported that implants with an RBM surface did not make a statistically significant difference in osseointegration levels compared to the SLA surface implants. In addition, the osseointegration levels of the SLA surface implants were higher on a numerical level. This study has some limitations. In this study, the rat tibia model was considered suitable for this study due to its ease of application and use. Animals have been used successfully in implant research. However, the tibial bone cannot fully model the jawbone. In addition, the structure of the tibia bone differs from that of the jawbone. The tibia is encircled by well-vascularized and bulky muscles. There are differences between experimental rat studies and human studies in skeletal morphology, bone tissue maturation, bone turnover, and healing behavior. The response of the tibia-femur long bones to graft-implant application may differ from that of the mandible-maxilla due to differences in their osteogenic potential. The method used in this study did not allow for a comprehensive investigation of the relationship between graft-implant application and peri-implant bone tissue, including molecular mechanisms. While experimental animal studies are necessary to clarify the relationship between bone and implant surfaces, the data obtained can only be used to predict pathways in humans. The study did not evaluate the long-term success or survival rate of the implants, which is an important criterion for determining implant success (25, 26).

In conclusion, in this study, the effect of simultaneous placement of implants with different surface characteristics and graft material on the level of osseointegration was evaluated. The analyses demonstrated that, when machined, SLA-, and RBM-surfaced implant groups were compared, similar levels of osseointegration were observed at the bone–implant interface in the RBM and SLA groups. However, RBM-surfaced implants treated with calcium phosphate blasting and SLA-surfaced implants subjected to sandblasting and acid etching exhibited better osseointegration than machined-surfaced implants. These findings may be attributed to the increased implant surface area achieved through these surface modification techniques, thereby enhancing the retention of the graft material. Nevertheless, further studies are required to more comprehensively elucidate the relationship between osseointegration, implant surface characteristics, and graft material.

Competing Interests

The authors have no competing interests to disclose with respect to the authorship or publication of this article.

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