https://doi.org/10.52973/rcfcv-e35695 Revista Científica, FCV-LUZ / Vol. XXXV

Evaluation of Osseointegration of Trabecular Titanium Implants Produced with Porous Metal Technology: An Experimental Study

Evaluación De La Osteointegración De Implantes Trabeculares De Titanio Fabricados Con Tecnología De Metal Poroso: Un Estudio Experimental

Erhan Cahit Ozcan[1], *Murat Tanrisever*[2,*], *Yildiz Aydin*[3], *Bahar Tekin*[3], *Asli Sagsoz*[4], *Alihan Bozoglan*[3], *Umit Koray Can*[5], *Serkan Dundar*[3,α]

[1]*Firat University, Faculty of Medicine, Department of Esthetic, Plastic and Recosntructive Surgery, 23119, Elazig, Turkiye*
[2]*Firat Univeristy, Faculty of Veterinary Medicine, Department of Surgery, Elazig, 23119, Turkiye*
[3]*Firat University, Faculty of Dentistry, Department of Periodontology, 23119, Elazig, Turkiye*
[α]*Firat University, Institute of Sciences, Department of Statistics, 23119, Elazig, Turkiye*
[4]*Ministry of Health Bursa Dua Cinari Oral and Dental Health Center, 16110, Bursa, Turkiye*
[5]*Turkish Jockey Club Elazig Racecourse Horse Hospital, 23350, Elazig, Turkiye*
**Corresponding Author: mtanrisever@firat.edu.tr*

ABSTRACT

Trabecular titanium (TM) implants produced with porous metal technology are used in dental implant treatments due to their resemblance to cancellous bone and their physical and mechanical properties. The objective of this study was to perform a histological assessment and comparison of the bone–implant contact (BIC) rates between trabecular metal (TM) implants and conventionally machined-surface implants in rat femurThe study was conducted using twenty healthy adult male Sprague-Dawley rats, which were randomly allocated into two equal groups: one serving as the control group and the other receiving trabecular metal (TM) implants. All implants were surgically placed into the right femora of the rats. A curved incision approximately 10-15 mm long was made on the anterolateral aspect of the right knee. The knee joint capsule, formed by the femur and tibia, was dissected. Following this procedure, the patella was subluxed, exposing the intercondylar fossa of the femur for implant placement. Following a 4-week healing period, undecalcified histomorphometric analyses of the samples were performed. BIC (%) measurements were conducted in the histomorphometric evaluations. Group comparisons were analyzed using the Student's t-test. TM implants exhibited an average BIC of 37.13%, while standard cylindrical implants had an average BIC of 29.13%, with a significant statistical difference between the two groups ($P < 0.05$). Within the limitation of this study titanium implants produced with TM technology have higher percentages of BIC than standard cylindrical titanium implants.

Key words: Titanium implants; trabecular titanium implant; porous metal; osseointegration; bone implant connection

RESUMEN

Los implantes de titanio trabecular (TM) producidos con tecnología de metal poroso se utilizan en tratamientos de implantes dentales debido a su semejanza con el hueso esponjoso y sus propiedades físicas y mecánicas. El objetivo de este estudio fue comparar los niveles de conexión hueso-implante (BIC) de los implantes TM con los de los implantes de superficie mecanizada producidos convencionalmente en fémur de rata mediante métodos histológicos. Se utilizaron veinte ratas Sprague-Dawley macho adultas sanas en el estudio. Las ratas se dividieron en 2 grupos iguales: controles e implantes TM. Los implantes se colocaron quirúrgicamente en los huesos del fémur derecho de todas las ratas. Se realizó una incisión curva de aproximadamente 10-15 mm de largo en el aspecto anterolateral de la rodilla derecha. Se diseccionó la cápsula de la articulación de la rodilla formada por el fémur y la tibia. Después de este procedimiento, se subluxó la rótula y se expuso la fosa intercondilar del fémur para la colocación del implante. Después de un período de curación de 4 semanas, se realizaron análisis histomorfométricos no descalcificados de las muestras. Se realizaron mediciones de BIC (%) en las evaluaciones histomorfométricas. Los datos se compararon utilizando la prueba t de Student. El porcentaje promedio de BIC (%) se registró en 37,13% en implantes TM y 29,13% en implantes cilíndricos estándar, y se detectó una diferencia estadísticamente significativa entre los grupos ($P < 0{,}05$). Dentro de las limitaciones de este estudio, se encontró que los implantes de titanio producidos con tecnología TM tenían porcentajes de BIC más altos que los implantes de titanio cilíndricos estándar.

Palabras clave: Implantes de titanio; implante trabecular de titanio; metal poroso; osteointegración; conexión hueso-implante

Recibido: 07/05/2025 Aceptado:21/07/2025 Publicado: 26/08/2025

INTRODUCTION

Titanium implants have important clinical advantages in, for example, aesthetics, comfort, and function and are extensively utilized in the field of oral health care and craniofacial restoration [1]. Since the 1970s, much work has been done on the development of titanium implants in dentistry and craniofacial surgery. Today, titanium implants have become an indispensable part of oral and maxillofacial surgery and dentistry clinics and are also widely used in treatment protocols [2]. The use of titanium dental implants has undergone a dynamic change in treating patients through modern treatment protocols, and long-term success rates have been reported during follow-ups [3 , 4 , 5].

With the widespread use of titanium implants, many studies have been conducted on success criteria. The long-term maintenance of the bone–implant interface (BIC) is acknowledged as a critical determinant of implant success. Multiple variables influence the osseointegration process between bone tissue and titanium dental implant surfaces, including bone density and volume, implant macrodesign and geometry, mechanical loading environment, and surface characteristics. Optimal bone–implant interaction is strongly influenced by the surface topography, chemical composition, loading characteristics, and hydrophilicity of the implant. These factors can influence protein adsorption on the titanium implant surface, osteoblast activity, and the formation of new bone tissue [6 , 7 , 8].

Titanium implants have advantages, such as improved aesthetics and function, no damage to adjacent teeth, and significant clinical effects. They are also extensively utilized in dental clinical practice for both fully and partially edentulous patients, as well as in maxillofacial prosthetics. However, certain limitations in the application areas can arise due to factors such as incomplete osseointegration supply, peri-implant bone resorption, and the occurrence of infection symptoms between bone implants [5]. To overcome these limitations and improve the long-term success of implants, considerable research has concentrated on the geometrical properties of dental implants, resulting in the development of diverse surface modifications for titanium implants.

Recently, dental implants have been developed with a range of surface compositions and roughness levels. [6 , 7 , 8]. The topographical features of the implant surface play a critical role in osteoblast adhesion and differentiation during the early phase of osseointegration, as well as in the regulation of long-term bone remodeling. The primary goal of biomedical research on surface modifications is to enhance initial osseointegration and sustain long-term bone–implant contact (BIC) by preventing peri-implant bone resorption [9]. Numerous surface modification techniques have been developed for titanium implants to enhance the longevity and success of the implant–bone interface. Different methods have been developed to increase the surface roughness or apply osteoconductive coatings to titanium implants [10].

In addition to recent advances in implant surface technology, trabecular metal (TM) production technology has provided a new perspective on implant production. The TM architecture is similar to that of cancellous bone, and its physical and mechanical properties are similar to those of other prosthetic materials. New bone can grow around the TM and fill most of the existing pore spaces. TM technology is a manufacturing technique developed for use in a variety of clinical applications in orthopedics, including spine devices, osteonecrosis treatment, and hip reconstruction [11].

The purpose of the present study was to compare the BIC levels (%) of titanium implants produced with TM technology with those of machine-surfaced implants produced with traditional production in rat femurs using nondecalcified histological methods.

MATERIAL AND METHODS

Animals and study design

All experimental procedures and animal care practices were performed at the Firat University Experimental Research Center, Elazig, Turkiye. Ethical permission for the study was obtained from the Firat University Animal Experiments Ethics Committee (Protocol Number: 2017/48, Date: 21.04.2017). All rats (*Rattus norvegicus*) used in the experiment were provided by the Firat University Experimental Research Center. All phases of the study were conducted in strict accordance with the World Medical Association's Declaration of Helsinki, ensuring the ethical treatment and protection of laboratory animals used in experimental research.

The study included twenty healthy adult male Sprague-Dawley rats, aged between 1 and 1.5 years. At the beginning of the experimental phase, the average body weight (WL, Shimadzu, Japan) of the rats was 500–550 g. The animals were housed in plastic cages in rooms with 24-hour temperature controls. The rats were allowed ad libitum access to food and water throughout the experiment. Animals were housed under a controlled 12-hour light/12-hour dark cycle. The rats were randomly selected and divided into the following 2 study groups, with 2 similar average weights:

Titanium implants produced with TM technology: TM titanium implants (GÖR Group Medical Corporation, Ankara, Türkiye) with a length of 6 mm and a diameter of 3 mm were placed in the corticocancellous bone of the right femur of the rats.

Standard cylindrical implants (Controls): Standard cylindrical implants (GÖR Group Medical Corporation, Ankara, Türkiye) of 3 mm in diameter and 6 mm in length were placed in the right femur corticocancellous bone of the rats.

Surgical procedure

Intramuscular administration of Ketamine Hydrochloride (35 mg/kg) and Xylazine (5 mg/kg) was employed to induce general anesthesia. Surgical interventions were conducted under strictly aseptic conditions to ensure sterility throughout the procedures. Before the surgery, following the induction of general anesthesia, the operative area was shaved and disinfected with povidone–iodine. An incision approximately 10–15 mm in length was created along the anterolateral aspect of the right knee. The capsule encasing the tibia and femur was carefully dissected, opened to facilitate access to the underlying structures. The patella was then partially shifted to allow visualization of the femoral intercondylar notch. Subsequently, implant sockets were prepared using a drill (NSK, Japan) at 600 rpm, with intermittent saline irrigation to prevent thermal injury. In order to inhibit cartilage development on the implant surfaces, titanium implants were inserted through the articular cartilage and secured in the corticocancellous region of the femur, providing initial mechanical stability. A total of 20 implants, each 3 mm in diameter and 6 mm in length, were implanted into the femoral bone, with one implant inserted into each femur. Insertion torques were measured as 25 N/cm for standard cylindrical implants, while insertion torques were measured as 40 N/cm for trabecular implants. The implants were evenly distributed between the two experimental groups, with 10 allocated to each.

To maintain procedural uniformity, all surgeries were conducted atraumatically by the same operator. Following implant placement, the knee joint capsule was repositioned, and subcutaneous tissue, skin and the fascia were closed using 4-0 polyglactin absorbable sutures. Upon completion of the surgical procedures, all animals received intramuscular administration of antibiotics (40 mg/kg Penicillin) and analgesics (1 mg/kg Tramadol hydrochloride) for a duration of three d.

Histomorphometrical analyses

During the experimental period, no fatal or nonfatal complications were detected. The rats were euthanized 4 weeks after surgery. The implants were carefully dissected from the surrounding bone, muscle, and soft tissues, and subsequently fixed in 10 % formaldehyde solution for preservation. Following the fixation period, the specimens were embedded in 2-hydroxyethyl methacrylate resin to facilitate sectioning of the undecalcified bone and titanium. For histological and histomorphometric evaluations, each sample was ground using a precision grinder to obtain a 50 µm-thick section, which was then analyzed under a light microscope (Nikon, Japan). Toluidine blue staining was used for the histological analyses. The procedures were performed at the Research Laboratory of the Faculty of Dentistry, Erciyes University, Kayseri, Turkey. Following the completion of these procedures, histological and histomorphometric analyses were conducted to evaluate the bone tissue response around the implant siteHistopathological and histomorphometric analyses of BIC were conducted using an image analysis system (Nikon, Japan) at the Department of Medical Microbiology Laboratory, Faculty of Medicine, Firat University. In each section, BIC was quantified as the percentage of the total implant surface length that was in direct contact with bone tissue. [8].

Statistical analysis

Statistical analysis were conducted using SPSS software version 23.0 for Windows (SPSS Inc.). Data normality was evaluated with the Shapiro–Wilk and Kolmogorov–Smirnov tests, which confirmed that the data followed a normal distribution. BIC values between groups were compared using the Student's t-test. For all analyzed data, the mean ± standard deviation was determined for each group, with P values < 0.05 considered statistically significant.

RESULTS AND DISCUSSION

No cases of mortality, infection, or wound dehiscence were observed during this protocol. The BIC parameters for both groups are shown in TABLE I.

TABLE I
Bone implant connection ratio (%) of the groups after the non decalcified histopathological analysis

Parameter	Groups	Mean	Std. Dev	P*
Bone Implant Connection	Control (n=10)	29.13	6.53	0.027
	Trabecular (n=10)	37.13	6.45	

* Student T test (P<0.05 P=0.027).

The average BIC values were found to be 37.13% in the TM implant group and 29.13% in the control group with standard cylindrical implants. Statistical analysis revealed a significantly higher mean BIC percentage in the TM implant group compared to the standard implant group (FIGS. 1 A, B, C) and (FIGS. 2. A, B, C).

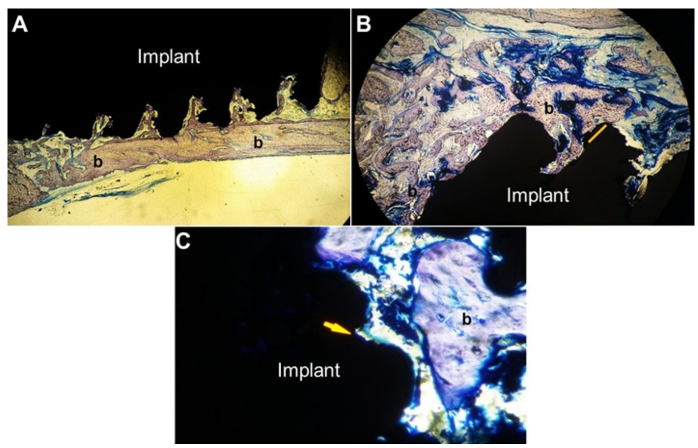

FIGURE 1. Undecalcified histological image of the conventionally produced implant. A: 2X, B: 4X, C: 10 X Magnification (X: Ten times magnification). b: Bone, Yellow Line: Bone contact with the implant. Yellow arrow: Bone not contact the implant. BIC: Bone Implant Conneciton ratio (%): Bone implant contact length/ Total implant surface length X 100

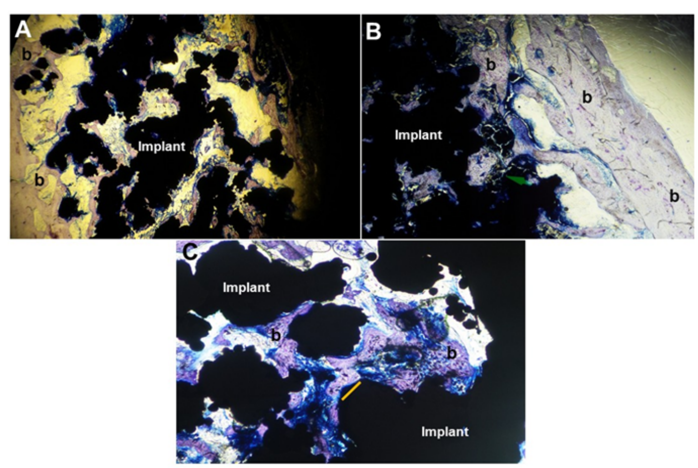

FIGURE 2. Undecalcified histological image of the trabecular metal technology produced implant. A: 2X, B: 4X, C: 10 X Magnification (X: Ten times magnification). b: Bone, Yellow Line: Bone contact with the implant. Geen Arrow: Bone tissue embedded in the implant trabecula. BIC: Bone Implant Conneciton ratio (%): Bone implant contact length/ Total implant surface length X 100

Osseointegration is defined as the process involving intimate interaction between an implant and the surrounding bone tissue, leading to the mechanical fixation of the implant. [12]. The most current research on dental implants has focused on various surface treatments to develop a secure implant surface that promotes osseointegration to increase surgical success rates in practice [13]. Various implant surface modification techniques have been developed to enhance implant–bone integration success. An ideal implant surface should promote peri-implant bone healing and facilitate the formation of solid and well-organized mature bone, resulting in an osseointegrated implant that can resist the stresses of occlusal loading [14]. The specific effects of titanium implant surface chemistry and topography on early osseointegration processes have not yet been fully clarified. Numerous methods have been developed and continue to be refined to explore this relationship [15].

The effects of titanium implants produced using TM technology and traditional cylindrical titanium implants on osseointegration were assessed histologically in this study. A significantly higher average BIC value was obtained in TM implants than in standard cylindrical implants. Consistent with our findings, previous studies have indicated that porous surfaces serve as effective alternatives to rough implant coatings, enhancing the interface strength between bone and implant material [11 , 16]. As a consequence, implant outcomes become more effective and stable. Additional benefits of porous surfaces include reduced initial healing time, improved fixation, and enhanced cellular adhesion and vascularization. [11]. In contrast, solid (nonporous) implants permit bone growth only on their surfaces. Porous implants, however, are designed to achieve stabilization through bone ingrowth within their pores, thereby promoting prolonged osseointegration. This surface modification technique has been employed for over a decade to enhance the stability of orthopedic implants [16].

In addition to osteoconduction occurring in the pores around the implant, it has been suggested that preosteoblasts in blood clots within the TM implant biomaterial transform into osteoblasts by combining with calcium to form calcified bone tissue in the pores and internal healing chambers of the TM implant. This process, involving both bone growth and ingrowth healing, is referred to as osseoincorporation [11]. In a study histologically and clinically examining the effects of TM implants on bone healing, the results supported the concept of osseoincorporation. The results of the study showed that TM technology facilitates neovascularization of the material and supports bone growth and neoformation within the implant. The highest value for BIC was seen in the TM group, which was significantly higher than for the standard titanium implant [17]. In a clinical study by de Arriba *et al*. [18], they histomorphometrically evaluated progressive bone growth into TM implants in human jaws. The results showed that the combination of conventional surface BIC (via geometric interference) supported by the formation of an intramembranous-like bone in the interconnected TM network was directly compatible with osseoincorporation. This process resulted from the formation of an osteogenic tissue network in the TM, resulting in vascular bone volume levels.

Recently, porous-surface implants have been extensively studied in various animal models to assess their effectiveness in enhancing osseointegration. Data synthesis and analysis from selected studies indicate that porous-surface implants may significantly enhance the percentage of bone fill during osseointegration compared to their nonporous counterparts. A similar effect may also occur for BIC [19]. In histomorphometric analysis, BIC is defined as the percentage of the implant surface directly apposed to bone. However, for porous-surface implants, this measurement encompasses both the perimeter and the interior surfaces of the pores. [20]. In this study, as in similar studies, we used the BIC value (%), which is one of the most commonly used methods to evaluate the stability and osseointegration levels of titanium implants [8 , 21 , 22 , 23].

A study by Lee *et al*. [24], evaluation of the stability and histological evidence of osseoincorporation in TM dental implants has demonstrated that porous implant surfaces positively influence bone formation compared to nonporous surfaces. Another study concluded that the TM implant material enhances bone ingrowth, contributing to secondary implant stability, and proposed that it may also help resist peri-implant inflammation [25]. In an 8-week *in vivo* study, the BIC percentages for implants placed in rabbit femoral condyles were 47.6 ± 8% for titanium implants and 57.9 ± 6.5% for TM implants with tapered screws. A statistically significant higher BIC percentage was obtained for TM implants [20]. In another *in vivo* study at 4, 8, and 12 weeks, BIC percentage values of 42.8 ± 18.8 for TM implants and 13.7 ± 6.1 for standard cylindrical titanium implants were obtained at week 4, and BIC percentage values of 53.9 ± 13.2 for TM implants and 35.6 ± 9.6 for standard cylindrical titanium implants were obtained at week 12 [26].

The results of these studies show that BIC values in TM implants have improved significantly. These data show the superiority of TM implants in terms of osseointegration and implant stability. In parallel with the results of these studies, our study found that the statistically significantly higher average BIC percentage obtained in TM implants reflects the positive effect of these implants on bone–implant fusion. At the conclusion of the 4-week follow-up, the average BIC percentage was 37.13% for TM implants and 29.13% for standard cylindrical implants. These findings are consistent with those reported in previous studies [20 , 24 , 26].

Based on the results of this study, the significantly higher percentage of bone–implant contact observed in TM implants compared to controls can be attributed to the enhanced surface roughness of the TM implants, which promotes superior bone–implant integration [23 , 27].

COCLUSION

This study showed that there was a statistically significant difference between the groups in the percentage of bone–implant fusion in the histological examination of TM and standard cylindrical implants. Within the limits of this study, higher success was observed in terms of osseointegration on TM implant surfaces compared to standard cylindrical titanium implants. Implants produced with the TM method may have more successful clinical results. More studies are needed to fully understand the osseointegration process in implants produced with TM technology.

ACKNOWLEDGEMENT

The authors wish to thanks GÖR Group Medical Corporation, Ankara, Turkiye for manufacturing the implants

Funding

There is no funding.

Ethics approval and consent to participate

Firat University Animal Experiment Local Ethic Comittee, Elazığ, Türkiye (approval number: 2017/48; date:21.04.2017).

Conflicts of interest

The authors declare no competing of interest.

BIBLIOGRAPHIC REFERENCES

[1] Yang BC, Zhou XD, Yu HY, Wu Y, Bao CY, Man Y, Cheng L, Sun Y. Advances in titanium dental implant surface modification. West China Journal of Stomatology. [Internet]. 2019; 37(2):124-129. doi: https://doi.org/g65h4g

[2] Alghamdi HS, Jansen JA. The development and future of dental implants. Dent. Mater. J. [Internet]. 2020; 39(2):167-172. doi: https://doi.org/gqnkzm

[3] Albrektsson T, Buser D, Sennerby L. Crestal bone loss and oral implants. Clin. Implant Dent. Relat. Res. [Internet]. 2012; 14(6):783-791. doi: https://doi.org/f22q7f

[4] Buser D, Sennerby L, De Bruyn H. Modern implant dentistry based on osseointegration: 50 years of progress, current trends and open questions. Periodontol. 2000. [Internet]. 2017; 73(1):7-21. doi: https://doi.org/f3t8sz

[5] Annunziata M, Guida L. The Effect of Titanium Surface Modifications on Dental Implant Osseointegration. Front. Oral Biol. [Internet]. 2015; 17:62-77. doi: https://doi.org/pzwk

[6] Le Guehennec L, Goyenvalle E, Lopez-Heredia MA, Weiss P, Amouriq Y, Layrolle P. Histomorphometric analysis of the osseointegration of four different implant surfaces in the femoral epiphyses of rabbits. Clin. Oral Implants Res. [Internet]. 2008; 19(11):1103-1110. doi: https://doi.org/bxgbv2

[7] Le Guéhennec L, Soueidan A, Layrolle P, Amouriq Y. Surface treatments of titanium dental implants for rapid osseointegration. Dent. Mater. [Internet]. 2007; 23(7):844-854. doi: https://doi.org/b2rw2d

[8] Dundar S, Yaman F, Gecor O, Cakmak O, Kirtay M, Yildirim TT, Karaman T, Benlidayi ME. Effects of Local and Systemic Zoledronic Acid Application on Titanium Implant Osseointegration: An Experimental Study Conducted on Two Surface Types. J. Craniofac. Surg. [Internet]. 2017; 28(4):935-938. doi: https://doi.org/gbh973

[9] Smeets R, Stadlinger B, Schwarz F, Beck-Broichsitter B, Jung O, Precht C, Kloss F, Gröbe A, Heiland M, Ebker T. Impact of Dental Implant Surface Modifications on Osseointegration. Biomed. Res. Int. [Internet]. 2016; 2016:6285620. doi: https://doi.org/f9jp5f

[10] Stanford CM. Surface modifications of dental implants. Aust Dent J. [Internet]. 2008; 53(Suppl1):S26-S33. doi: https://doi.org/bgsg5v

[11] Bencharit S, Byrd WC, Altarawneh S, Hosseini B, Leong A, Reside G, Morelli T, Offenbacher S. Development and applications of porous tantalum trabecular metal-enhanced titanium dental implants. Clin. Implant Dent. Relat. Res. [Internet]. 2014; 16(6):817-826. doi: https://doi.org/gp3dgq

[12] Velasco-Ortega E, Ortiz-Garcia I, Jiménez-Guerra A, Núñez-Márquez E, Moreno-Muñoz J, Rondón-Romero JL, Cabanillas-Balsera D, Gil J, Muñoz-Guzón F, Monsalve-Guil L. Osseointegration of Sandblasted and Acid-Etched Implant Surfaces. A Histological and Histomorphometric Study in the Rabbit. Int. J. Mol. Sci. [Internet]. 2021; 22(16):8507. doi: https://doi.org/gp5nmb

[13] Yeo IL. Modifications of Dental Implant Surfaces at the Micro- and Nano-Level for Enhanced Osseointegration. Materials. [Internet]. 2020; 13(1):89. doi: https://doi.org/gmwpwg

[14] Blatt S, Pabst AM, Schiegnitz E, Hosang M, Ziebart T, Walter C, Al-Nawas B, Klein MO. Early cell response of osteogenic cells on differently modified implant surfaces: Sequences of cell proliferation, adherence and modified implant surfaces: Sequences of cell proliferation, adherence and differentiation. J. Craniomaxillofac. Surg. [Internet]. 2018; 46(3):453-460. doi: https://doi.org/gc4zdt

[15] Luke Yeo IS. Dental Implants: Enhancing Biological Response Through Surface Modifications. Dent. Clin. North. Am. [Internet]. 2022; 66(4):627-642. doi: https://doi.org/gtq9h2

[16] Romanos GE, Delgado-Ruiz RA, Sacks D, Calvo-Guirado JL. Influence of the implant diameter and bone quality on the primary stability of porous tantalum trabecular metal dental implants: an *in vitro* biomechanical study. Clin. Oral Implants Res. [Internet]. 2018; 29(6):649-655. doi: https://doi.org/pzwn

[17] Bencharit S, Morelli T, Barros S, Seagroves JT, Kim S, Yu N, Byrd K, Brenes C, Offenbacher S. Comparing Initial Wound Healing and Osteogenesis of Porous Tantalum Trabecular Metal and Titanium Alloy Materials. J. Oral. Implantol. [Internet]. 2019; 45(3):173-180. doi: https://doi.org/pzwp

[18] de Arriba CC, Alobera Gracia MA, Coelho PG, Neiva R, Tarnow DP, Del Canto Pingarron M, Aguado-Henche S. Osseoincorporation of Porous Tantalum Trabecular-Structured Metal: A Histologic and Histomorphometric Study in Humans. Int. J. Periodontics Restorative Dent. [Internet]. 2018 [cited 05 Apr 2025]; 38(6):879–885. Available in: https://goo.su/Ucon1

[19] Özcan EC, Aydin MA, Dundar S, Tanrisever M, Bal A, Karasu N, Kirtay M. Biomechanical Investigation of the Osseointegration of Titanium Implants With Different Surfaces Placed With Allogeneic Bone Transfer. J. Craniofac. Surg. [Internet]. 2024; 35(7):2184-2188. doi: https://doi.org/pmwx

[20] Al Deeb M, Aldosari AA, Anil S. Osseointegration of Tantalum Trabecular Metal in Titanium Dental Implants: Histological and Micro-CT Study. J. Funct. Biomater. [Internet]. 2023; 14(7):355. doi: https://doi.org/pzwr

[21] Dundar S, Yaman F, Bozoglan A, Yildirim TT, Kirtay M, Ozupek MF, Artas G. Comparison of Osseointegration of Five Different Surfaced Titanium Implants. J. Craniofac. Surg. [Internet]. 2018; 29(7):1991-1995. doi: https://doi.org/pmw5

[22] Calvo-Guirado JL, Satorres-Nieto M, Aguilar-Salvatierra A, Delgado-Ruiz RA, Maté-Sánchez de Val JE, Gargallo-Albiol J, Gómez-Moreno G, Romanos GE. Retraction Note: Influence of surface treatment on osseointegration of dental implants: histological, histomorphometric and radiological analysis *in vivo*. Clin. Oral Investig. [Internet]. 2024; 28(1):118. doi: https://doi.org/pzws

[23] Kreve S, Ferreira I, da Costa Valente ML, Dos Reis AC. Relationship between dental implant macro-design and osseointegration: a systematic review. Oral Maxillofac. Surg. [Internet]. 2024; 28(1):1-14. doi: https://doi.org/pzwt

[24] Lee JW, Wen HB, Battula S, Akella R, Collins M, Romanos GE. Outcome after placement of tantalum porous engineered dental implants in fresh extraction sockets: a canine study. Int. J. Oral Maxillofac. Implants. [Internet]. 2015 [cited 05 Apr 2025]; 30(1):134-142. Available in: https://goo.su/4Sps0

[25] Gasbarra E, Iundusi R, Perrone FL, Saturnino L, Tarantino U. Densitometric evaluation of bone remodelling around Trabecular Metal Primary stem: a 24-month follow-up. Aging Clin. Exp. Res. [Internet]. 2015; 27(Suppl 1):S69-S75. doi: https://doi.org/pzww

[26] Fraser D, Mendonca G, Sartori E, Funkenbusch P, Ercoli C, Meirelles L. Bone response to porous tantalum implants in a gap-healing model. Clin. Oral Implants Res. [Internet]. 2019; 30(2):156-168. doi: https://doi.org/gx7ksq

[27] Lee JW, Wen HB, Gubbi P, Romanos GE. New bone formation and trabecular bone microarchitecture of highly porous tantalum compared to titanium implant threads: A pilot canine study. Clin. Oral Implants Res. [Internet]. 2018; 29(2):164-174. doi: https://doi.org/gts25s