OSSEOINTEGRATION OF DENTAL IMPLANTS: A REVIEW

Forna Norina[1]*

1 "Gr.T.Popa" University of Medicine and Pharmacy Iasi, Romania, Faculty of Dental Medicine

correspondent member of AOSR; full member of ASM

Corresponding author*:Forna Norina, Univ.Prof., PhD; profforna@gmail.com

Abstract

The osseointegration processes are based on post-implantation healing processes that are modeled by the activation by complex mechanisms of macrophages that leads to the differentiation of new osteoblasts on the implant surface. Factors influencing osseointegration include patient-related factors (systemic status), surgical factors (operating field asepsis, bone preparation time, operative trauma), and implant design factors (shape and dimensional characteristics, chemistry and surface topography, material). The quality of the implant biomaterial and the bone healing capacity followed by the bio-functional remodeling of the peri-implant tissues are the two major factors that ensure the maintenance of osseointegration and the quality of osteo-reception of dental implants. Research groups and manufacturers of implants with bioactive surfaces are focused on the increase of osseointegration by lowering the bacterial adhesion, while promoting the recruitment, adhesion and proliferation of osteogenic elements (osteoblast cells) and fibroblasts.

Key words: *osseointegration, dental implants, biomaterials, design, bone healing*

Introduction

The osseointegration of the dental implants is defined as "direct anatomical and functional junction between the reshaped bone and the surface of the implant that was loaded" (1). The notion of the implant biointegration implies the absence of the fibrous connective layer at the bone-implant interface, while currently it is preferred to use the notion of implant acceptance, assuming an almost direct and functional connection between a vital bone and the implant inserted in bone (2).

The relationship between osseointegration and the failure rate of the dental implants concerned both practitioners and research groups. Although the failure rate of implants is extremely low, 1-2% of implants are associated with insufficient osseointegration within a few months of implantation (3). Even under conditions of successful osseointegration, secondary failures can occur, mostly caused by periimplantitis, in 5% of patients in whom implant-prosthetic therapy has been performed (3). The failure rate in primary implant osseointegration may increase in patients with diabetes, osteoporosis, bisphosphate treatment, or radiation therapy.

The osseointegration processes are based on post-implantation healing processes that are modeled by the activation by complex mechanisms of macrophages that leads to the differentiation of new osteoblasts on the implant surface (4). Osseointegration involves a series of complex physiological mechanisms similar to those occurring in the healing processes associated with fracture, as the trepanation of the alveolar bone during implant procedures is associated with bone trauma followed by a distinct phase of wound healing (5). Osteogenesis can be distant osteogenesis (bone grows toward the implant from the cavity adjacent to the implant) or contact osteogenesis (by depositing osteogenic cells on the implant surface) that ensures secondary implant stability. The first new bone may be found on the implant surface around 1week post-implantation, bone remodeling starts at between 6 and 12 weeks and continues throughout life (6).

Factors influencing osseointegration include patient-related factors (systemic status), surgical factors (operating field asepsis, bone preparation time, operative trauma), and implant design factors (shape and dimensional characteristics, chemistry and surface topography, material). The assessment of the properties of the different biomaterials and of the factors that influence bone repair is essential to the clinical success of dental implants (7). The quality of the implant biomaterial and the bone healing capacity followed by the bio-functional remodeling of the peri-implant tissues are the two major factors that ensure the maintenance of osseointegration and the quality of osteo-reception of dental implants. For the category of patients at risk it is necessary to use implants with bioactive surfaces (8). The improvement of the rate of osseointegration is achieved by changing the surface of titanium implants. Initially, the changes obtained by mechanical processing of titanium surfaces were associated with osseointegration obtained within 3-6 months, in relation to the location and quality of the bone (9).

The processes of osseointegration can be investigated both in terms of osseointegration into bone tissue and in terms of osseointegration in contact with bone replacement materials, in immediate implantation techniques consecutively with guided bone regeneration techniques. To improve osseointegration in bone areas with severe bone resorption, bone regeneration techniques are used in the pro-implant stage.

Bone grafting materials (xenografts, allografts, alloplastics) that serve as a matrix for the formation of new bone tissue, becoming integrated into the newly formed bone and being slowly removed as they are progressively replaced by neoosseous tissue (10). In the case of attachment by osseointegration, there is direct contact between the implant surface and the peri-implant bone tissue

Factors and parameters that influence the osseointegration processes of the dental implants are further.presented. *Biomaterials of dental implants*.

According to the material from which the dental implants are made, they can be divided into three categories (table I):

-metallics (pure titanium, titanium alloys, gold alloys);

-ceramics (hydroxyapatite, zirconium, bioglasses);

-polymer (PMMA, PTFE, PE, PSF, PU).

The qualities and limits of dental implants are directly related to the mechanical, chemical properties, biocompatibility of the materials from which they are made.

The osseointegration attachment is favored by implants made of titanium. In biointegration (characteristic of zirconium implants and those with a surface covered with hydroxyapatite) there is a space between the bone tissue and the surface of the dental implant. In biointegration, bone tissue attaches to the corrosion layer on the implant surface. The fibrous attachment is unfavorable and is characteristic of clinical situations in which osseointegration does not take place (implant failure) is characterized by the complete encapsulation of the implant surface by the soft tissues.

Pure titanium implants may induce nonspecific immunomodulation and autoimmunity mechanisms, ie stress on the implant-bone interface during pregnancy transfer (due to the gradient difference between the modulus of elasticity of the titanium implant and the peri-implant bone tissue) which can lead to peri-implant bone loss (11). Data from the literature show that pure titanium and titanium alloys demonstrate similar osseointegration and biomechanical anchoring (12). Ti-6Al-4V is one of the most commonly used titanium alloys in the manufacture of the dental implants. This material is known for its high resistance to fatigue and corrosion but also low density (13). Titanium binary alloys, excepting Ti-10V, have a statistically similar biocompatibility with pure titanium (14, 15).

Ceramics have been introduced in the manufacture of dental implants due to a low percentage of cases of hypersensitivity to titanium and titanium alloys. They have the advantage of biocompatibility, aesthetic appearance similar to root surfaces and low affinity for bacterial plaque (16). Limitations of initial ceramics dental implants have led to the emergence of composite materials that have combined alumina with zirconium. Two types of such materials were produced: circumcision-reinforced alumina (ZTA), alumined zirconium with alumina particles (ATZ). The combination of these materials leads to materials that combine the hardness of alumina with the resistance to mechanical stress (eg shear) of zirconium (resistance to cracks and fractures) (16,17).

Zirconium implants are considered to have an increased potential for use in the coming years, given that research will demonstrate the possibilities of reducing mechanical failures. For zirconium implants osseointegration is lower comparing with titanium alloys, but can be optimized by modifying the surface roughness (eg laser modification) (18, 19). A review of literature data reported the absence of significant difference in the BIC values between titanium and machined zirconia implants, significantly better BIC values for acid etched zirconia implants compared with those of titanium implants, while unmodified zirconia implants showed favorable BIC values compared to modified-surface zirconia implants (20). Zirconia and titanium implants demonstrate a similar soft and bone tissue integration capacity, but titanium tended to show a faster initial osseointegration process compared to zirconia (21).

Polymer implants (PEEK) are considered a viable alternative to titanium implants, but new experimental studies are needed both to investigate chemical modulation and to find combinations that will increase the bone / implant interface and minimize stress distribution to the peri-implant bone (22, 23). The review of studies on the advantages and limitations of dental implants produced from polymers concludes the following (24): flexural strength is between 140-170 MPa; the fracture resistance of PEEK implants is superior to that attributed to zirconium or ceramic implants; superior biocompatibility of titanium alloy implants.

Table I. Dental implants materials categories (Osman et al.,2015)

	Material	Abreviation
I.	Metals	
I.1.	Titanium	CpTi
I.2.	Titanium alloys	Ti-6Al-4V Ti-6Al-7Nb Ti-5Al-2.5Fe Ti-15Zr-4Nb-2Ta-0.2Pd Ti-29Nb-13Ta-4.6Zr Roxolid (83%-87%Ti-13%-17%Zr)
I.3.	Other metals	
	Stainless steel Cr-Cb alloy Gold alloys Tantal	SS, 316LSS Vitaliu, Co-Cr-Mo Aliaje Au Ta
II.	Ceramics	
II.1	Alumina Hidroxyapatite Beta-Tricalcium phosphate Alumina with high zirconium content	Al2O3 HA, Ca10(PO4)10, (OH)2 Beta-TCP, Ca3(PO4)2 ZTA
II.2	Carbon	C Vitros LTI (izotropic la temperaturi scăzute) ULTI (izotropic la temperaturi ultrascăzute)
II.3.	Carbon-Silicone	C-Si
II.4.	Bioglass	SiO2/CaO/Na2O/P2O5
II.5.	Zirconium	ZrO2
III.	Polymers	
	Polymethyl Polytetrafluorethylene Polyethylene Polysulfonate Polyuretan	PMMA PTFE PE PSF PU

	Polyeter eter ketone	PEEK

Geometry, macro and microdesign of dental implants

The implant design includes macrodesign and microdesign (surface topography). Macrodesign and microdesign are some of the main factors influencing the osseointegration and primary stability of the implant, as well as the distribution of the peri-implant stress (25). Given that there are various geometric shapes and different thread designs, selecting an implant geometry to ensure optimal long-term stability is a challenge for implantologists (26). Finite element analysis (FEA) studies are an excellent tool for evaluating different models of complex implants with different materials and practically simulate clinical cases before conducting clinical trials (27, 28, 29). Each type of macrodesign has advantages and limitations. Cylindrical implants provide varying degrees of osseointegration and microscopic retention in relation to the surface condition and the manufacturing material or which covers the surface of the implant. Implants with threaded surface have the advantage of higher retention area between implant and bone and increased area of distribution of bone peri-implant stresses after functional loading. In the case of implants with perforated surface the titanium support area is the perforated area. This type of dental implants has multiple perforations on the lateral surfaces that favor the anchoring of the implant to the peri-implant bone tissues. Surface treatments influence micro-design and have a direct impact on the expansion of osseointegration processes. Implants with bioactive surfaces lead to an increase in the long-term bone-implant contact surface and to a reduction in marginal post-implantation resorption (30). Also, implants with bioactive surfaces offers the possibility to use early loading protocol, by accelerating the osseointegration processes (30). In the case of dental implants with changes in surface microtopography, there is an increase in bone-implant contact area, but also positive changes in growth, metabolism, cell migration and production of cytokines and growth factors by osteogenic cells (31). The manufacturers have proposed the transition from classic implants to bioactive implants that have major advantages, such as shortening the healing time and the participation of the implant in the normal tissue remodeling process. Categories of bioactive dental implants are as follows (Fig. 1):

-implants with modified surface by sandblasting and acid conditioning (SLA, Straumann Holding, Switzerland);

-implants with modified surface by blasting, acid conditioning and neutralization (FRIADENT, DENTSPLYImplants, Germany);

- implants with surface changes by crystal deposition (NanoTite and Osseotite, BIOMET 3i, USA);

- implants with surface modifications by laser techniques (LaserLo, (BioHorizons, USA);

-implants with surfaces modified by acid conditioning and blasting with titanium oxide (OsseoSpeed DENTSPLY Implants, Germany).

- implants with hydrophilic surfaces (SLA, Straumann Holding AG, Basel, Switzerland);

-implants with surface changes by coating with hydroxyapatite (AnyRidge, Megagen, South Korea);

-implants with surface changes by coating with hydroxyapatite and nanocomposite (SurfLink, Nano Bridging Molecules, Switzerland).

Straumann SLA implants (modified surface sandblasting and acid conditioning) have a higher bone-implant contact surface (50-60%) compared to titanium plasma spray modified implants (30-40%) or implants with electrochemically modified surfaces (20-25%) (32). A 1-year clinical study found a 100% survival rate for SLAactive implants compared to 96% for ALS implants and a post-implantation resorption of marginal bone of only 0.40 mm, with statistically significant differences compared to traditional ALS implants (33). Hydroxyapatite-coated implants using the SurfLink technique show superior biomechanical stability compared to the control group and a marginal periimplant bone resorption of only 0.27 mm, with statistically significant differences compared to control group (34). The increase of osseointegration rate was also reported in researches using growth factors embedded on dental implants surfaces (PDGF, TGF-β, VEGF, BMP) (35, 36, 37).

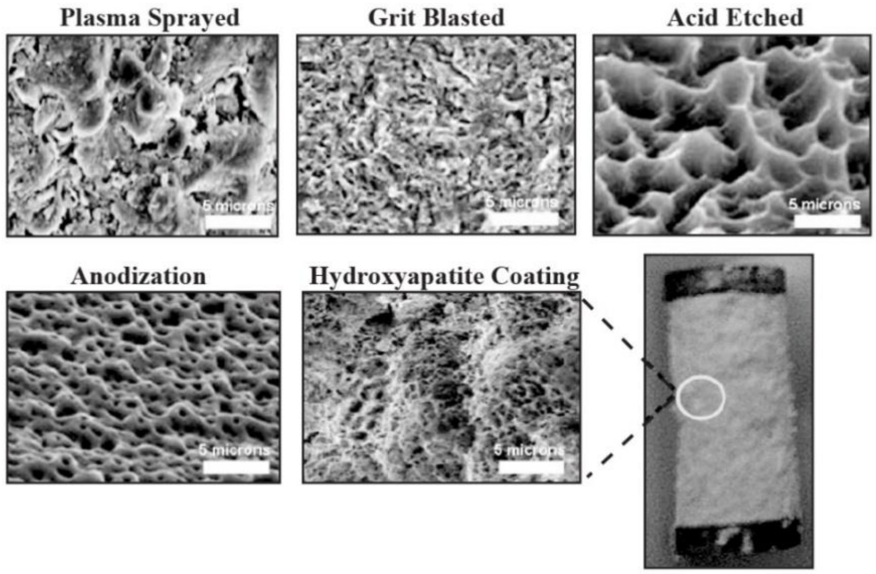

Fig.1. Tecniques for modifying the surfaces of dental implants (38)

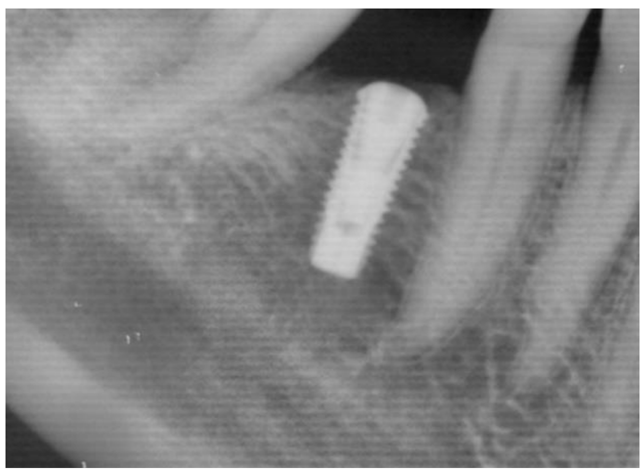

Fig.2. Osseointegration of dental implants modified by ceramics deposition (39)

Dimensional parameters

The highest failure rate is associated with short, high-diameter implants applied to low-density sites (40). One study investigated the role of dimensional parameters in influencing the implant success / failure rate (41). Regarding the length parameter, the maximum failure rate is associated with implants with a length of 11.5 mm (5.50%), followed by implants with lengths between minimum values of 10 mm and maximum values of 11.5 mm (4, 70%), respectively implants with a length of less than 10 mm (1.30%). Regarding the diameter of the implants, the maximum failure rate is associated with implants with a diameter below 3.75 mm (3.00%), followed by implants with a diameter with minimum values of 3.7 mm and maximum values of 4.5 mm (2, 00%), respectively implants with diameters over 4.5 mm (1.00%). The highest rate of implant failures was found for dental implants with lengths below 10mm (minimum values 7%, maximum values 25%) compared to dental implants with lengths over 10mm.

Current research on modifying and controlling the biomaterial-tissue interaction to improve the implant osseointegration process aims to capitalize on advances in regenerative medicine, using tissue engineering techniques and developing the field of intelligent biomaterials. In this context, the efforts of researchers and manufacturing companies are focused on the development of biocompatible surfaces, which favor cell adhesion and osseointegration processes. Research groups and manufacturers of dental implants intend further increasing of the osseointegration rate by focus on the lowering the bacterial adhesion, while promoting the recruitment, adhesion and proliferation of osteogenic elements (osteoblast cells) and fibroblasts (42).

Conclusions

- The role of osseointegration is the achievement of high stability of the dental implants, following bone healing processes.
- The initiation of osteogenesis and formation of young bone on the surface of the grafted bone areas are mandatory for the acceptance of the dental implants by host tissues.
- The osseointegration of the dental implants depends on the specific factors related both to the implant material properties and to the systemic and local status of patient.
- The biocompatibility of the implant material, geometry, macro and microdesign as well as dimensional parameters are major factors that influence the bone-implant contact and long-term successful osseointegration.

References

1. Palada I, A. M. Smarandache, M. Sabău, Conceptul de osteointegrare în implantologie. Acta Medica Transilvanica 2012; vol II, nr. 2, p. 113.
2. Vasilescu V. Teza de doctorat. Contributii la studiul materialelor metalice biocompatibile pentru implantologia orala. UMCD.2016.
3. Chrcanovic BR, T.Albrektsson, A.Wennerberg. Reasons for failures of oral implants. Journal of Oral Rehabilitation 2014,vol. 41,no.6:443–476.
4. Stanford C. Surface Modification of Biomedical and Dental Implants and the Processes of Inflammation, Wound Healing and Bone Formation. International Journal of Molecullar Science. 2010, 11: 354-363.
5. von Wilmowsky C, T. Moest, E. Nkenke, F. Stelzle, K. A. Schlegel. Implants in bone: part I. A current overview about tissue response, surface modifications and future perspectives. Oral and Maxillofacial Surgery 2014;vol.18,no.3:243–257.
6. Bosshardt DD, Chappuis V, Buser D. Osseointegration of titanium, titanium alloy and zirconia dental implants: current knowledge and open questions. Periodontol 2000. 2017;73(1):22-40.
7. Guglielmotti MB, Olmedo DG, Cabrini RL. Research on implants and osseointegration. Periodontol 2000. 2019;79(1):178-189.
8. Gomez-de Diego, Mang-de la Rosa MD, Romero Perez MJ, Cutando-Soriano A, Lopez-Valverde-Centeno A. Indications and contraindications of dental implants in medically compromised patients:update. Medicina Oral, Patologia Oral y Cirugia Bucal 2014, vol.19,no.5: 483– 489.
9. Abraham CM. A brief historical perspective on dental implants, their surface coatings and treatments. The Open Dentistry Journal 2014, vol.8, no.1:50–55.
10. Liu Y, Enggist L, Kuffer AF, Buser D, Hunziker EB. The influence of BMP-2 and its mode of delivery on the osteoconductivity of implant surfaces during the early phase of osseointegration. Biomaterials. 2007;28:2677–2686.
11. Vitalariu AM, Diaconu-Popa D, Monica Tatarciuc. Proprietăţile biomaterialelor realizate pentru realizarea implanturilor dentare- studiu retrospectiv. Romanian Journal of Medical and Dental Education. 2017; Vol.6(1): 31-45.
12. Shah F A, Trobos M, Thomsen P. Commercially pure titanium (cp-Ti) versus titanium alloy (Ti6Al4V) materials as bone anchored implants - Is one truly better than the other?. Mater Sci Eng C Mater Biol Appl. 2016;62:960-6.
13. Osman R B, Swain M V. A critical review of dental implant materials with an emphasis on titanium versus zirconia. Materials 2015;8(3):932-958.
14. Park YJ, Song YH, An JH et al. Cytocompatibility of pure metals and experimental binary titanium alloys for implant materials. J Dent 2013;41:1251–8.
15. Song YH, Kim MK, Park EJ et al. Cytotoxicity of alloying elements and experimental titanium alloys by WST-1 and agar overlay tests. Dent Mater 2014;30:977–83.
16. Mussano F, Genova T, Munaron L, Faga MG et al. Ceramic Biomaterials for Dental Implants: Current Use and Perspectives. 2016; DOI: 10.5772/62701.
17. Kohal R-J, Wolkewitz M, Mueller C. Alumina-reinforced zirconia implants: survival rate and fracture strength in a masticatory simulation trial. Clin Oral Implants Res [Internet]. 2010;21(12):1345–52.
18. Kohal RJ, Bächle M, Att W, Chaar S, Altmann B, Renz A, et al. Osteoblast and bone tissue response to surface modified zirconia and Ti implant materials. Dent Mater. 2013;29:763–76.

19. Prithviraj DR, Deeksha S, Regish KM, Anoop N. A systematic review of zirconia as an implant material. Indian J Dent Res 2012; 23: 643-649.
20. Hafezeqoran A, Koodaryan R. Effect of Zirconia Dental Implant Surfaces on Bone Integration: A Systematic Review and Meta-Analysis. Biomed Res Int. 2017;2017:9246721.
21. Roehling S, Schlegel KA, Woelfler H, Gahlert M. Zirconia compared to titanium dental implants in preclinical studies-A systematic review and meta-analysis. Clin Oral Implants Res. 2019;30(5):365-395.
22. Shariq N, Zohaib Khurshid BDS, Sana Zohaib BDS and Muhammad Sohail Zafar BDS. Bioactivity and Osseointegration of PEEK Are Inferior to Those of Titanium: A Systematic Review. Journal of Oral Implantology 2016; 42:6, 512-516.
23. Skirbutis G, Dzingutė A, Masiliūnaitė V, Šulcaitė G, Žilinskas J.PEEK polymer's properties and its use in prosthodontics. A review. Stomatologija. 2018;20(2):54-58.
24. Bathala L, Majeti V, Rachuri N, Singh N, Gedela S.The Role of Polyether Ether Ketone (Peek) in Dentistry - A Review. J Med Life. 2019 Jan-Mar;12(1):5-9.
25. Abuhussein H, Pagni G, Rebaudi A, Wang HL. The effect of thread pattern upon implant osseointegration. Clin Oral Implants Res. 2010;21:129-36.
26. Becker W, Becker BE, Hujoel P et al. Prospective clinical trial evaluating a new implant system for implant survival, implant stability and radiographic bone changes. Clin Implant Dent Relat Res 2013;15:15-21.
27. Korabi R, Shemtov-Yona K, Dorogoy A, et al. The Failure Envelope Concept Applied To The Bone-Dental Implant System. Scientific Reports. 2017;7:2051.
28. Brizuela-Velasco A, Pérez-Pevida E, Jiménez-Garrudo A et al. Mechanical Characterisation and Biomechanical and Biological Behaviours of Ti-Zr Binary-Alloy Dental Implants. BioMed Research International 2017; Article ID 2785863.
29. Demenko V, Linetskiy I, Nesvit K, et al. Importance of diameter-to-length ratio in selecting dental implants: a methodological finite element study. Computer Methods in Biomechanics and Biomedical Engineering. 2014; 17: 4, 443-449.
30. Smeets R, Bernd Stadlinger, Frank Schwarz, Benedicta Beck-Broichsitter, OleJung, Clarissa Precht, Frank Kloss, Alexander Gröbe, Max Heiland,Tobias Ebker. Impact of Dental Implant Surface Modifications on Osseointegration. Hindawi Publishing Corporation BioMed Research International; Volume 2016, Article ID 6285620.
31. Shibata Y, Y. Tanimoto. A review of improved fixation methods for dental implants—part I: surface optimization for rapid osseointegration. Journal of Prosthodontic Research 2015, vol. 59,no.1:20–33.
32. Buser D, S. F. M. Janner, J.-G. Wittneben, U. Bragger, C. A. Ramseier, G. E. Salvi. 10-Year survival and success rates of 511 titanium implants with a sandblasted and acid-etched surface: a retrospective study in 303 partially edentulous patients. Clinical Implant Dentistry and Related Research 2012, vol. 14, no. 6:839–851.
33. Wennerberg A, S. Galli, T. Albrektsson. Current knowledge about the hydrophilic and nanostructured SLActive surface. Clinical, Cosmetic and Investigational Dentistry 2011, vol.3:59–67.
34. Esposito M, I.Dojcinovic, L.Germonetal. Safety and efficacy of a biomimetic monolayer of permanently bound multi-phosphonic acid molecules on dental implants: 1 year post-loading results from a pilot quadruple-blinded randomised controlled trial. European Journal of Oral Implantology 2013, vol. 6, no. 3:227–236.
35. .Carreira AC, F.H.Lojudice, E.Halcsik, R.D.Navarro, M.C. Sogayar, J. M. Granjeiro. Bone morphogenetic proteins: facts, challenges, and future perspectives. Journal of Dental Research 2014, vol.93,no.4:335–345.
36. .Kim J-E, S.-S.Kang, K.-H.Choi et al.The effect of anodized implants coated with combined rhBMP-2 and recombinant human vascular endothelial growth factors on vertical bone regeneration in the marginal portion of the peri-implant. Oral Surgery, Oral Medicine, Oral Pathology and Oral Radiology 2013, vol. 115,no.6: 24–31.

37. Zhang W, Y. Jin, S. Qian et al.Vacuum extraction enhances rhPDGF-BB immobilization on nanotubes to improve implant osseointegration in ovariectomized rats. Nanomedicine: Nanotechnology, Biology, and Medicine 2014, vol.10,no.8:1809–1818.
38. Ahmed F, Rashid H, Farookhi S, Verma V, Mulyar Y, Khalifa M, Sheikh Z. Surface Modifications Of Endosseous Dental Implants By Incorporation Of Roughness And Hydroxyapatite Coatings. J Pak Dent Assoc. 2015; 24(4): 162-171.
39. Forna N. Aspects of the bioactive implants involved in periointegration concept. Proc. Rom. Acad., Series B, 2009, 2–3: 121–127.
40. Renouard F, Nisand D. Review- Impact of implant length and diameter on survival rates. Clin Oral Implants Res. 2006 Oct; 17 Suppl 2:35-51.
41. Raikar S, Talukdar P, Kumari S, Panda KS, Oommen VM, Prasad A. Factors Affecting the Survival Rate of Dental Implants: A Retrospective Study. J Int Soc Prev Community Dent. 2017 Nov-Dec; 7(6): 351–355.
42. Hanawa T. Zirconia versus titanium in dentistry: A review. Dent Mater J. 2020;39(1):24-36.