Porous Titanium Granules in Treatment of Intra-bony Defects: A Literature Review

Zahra Nateghi\textsuperscript{1}, Fatemeh Khalilian\textsuperscript{1*}, Noushin Janbakhsh\textsuperscript{1}, Mohammadreza Shirian\textsuperscript{2} and Amirali Shirian\textsuperscript{3}

\textsuperscript{1}Department of Periodontics, Shahid Beheshti University of Medical Sciences, Tehran, Iran.
\textsuperscript{2}DDS, Private Practice, Iran.
\textsuperscript{3}Department of Prosthodontics, Islamic Dental Azad University, Tehran, Iran.

Authors’ contributions
This work was carried out in collaboration between all authors. Authors ZN and AS designed the study and wrote the protocol. Author FK wrote the first draft of the manuscript. Author MS managed the literature searches. Author NJ wrote the final manuscript and revisions. All authors read and approved the final manuscript.

ABSTRACT

Background: This study aimed to do a review on the applications of porous titanium granules (PTG) in periodontal and non-periodontal treatments.

Methods: An electronic search was carried out in Google Scholar and PubMed databases using the key words “guided tissue regeneration”, “intrabony defects”, “porous titanium granules” and “moderate to advanced chronic periodontitis”. English articles published from 2006 to 2014 were searched.

Results: Porous titanium granules showed positive results in enhancing the outcome of treatment in medicine. Most of the relevant studies have been conducted using culture media or animal models.

Conclusion: It can be stated that PTGs have many applications in periodontal procedures due to their space maintaining capability, long-term substantivity, not requiring a membrane and biocompatibility.

*Corresponding author: E-mail: fatemehkhalilian1987@yahoo.com
Keywords: Guided tissue regeneration; intrabony defects; chronic periodontitis; porous titanium granules.

1. INTRODUCTION

Periodontal treatments are performed aiming to prevent further destruction of the periodontal tissue. The ultimate goal of these treatments is to regenerate the tissues injured or lost due to disease or trauma and reinstate their structure and function. The conventional surgical and non-surgical periodontal treatments often successfully inhibit the disease progression but the soft tissue recession due to treatment often compromises esthetics particularly in the anterior region. On the other hand, these treatments may not be very effective for eliminating the periodontal pockets in some areas; this may affect the long-term prognosis of the teeth. However, these complications may decrease by periodontal regenerative treatments and reconstruction of the lost structures. Guided tissue regeneration (GTR) was introduced with the biological concept that placement of a physical barrier prevents the migration of epithelial cells and connective tissue of the flap into the lesion and allows the periodontal ligament cells and mesenchymal cells to migrate on the root surface [1].

Successful periodontal regeneration includes regeneration of cementum, alveolar bone, periodontal ligament and connective tissue fibers attached to the root surface [2]. It is believed that the main barrier against the regeneration of periodontal tissues following the conventional periodontal treatment is the faster migration of epithelial cells and/or gingival connective tissue cells into the lesion compared to mesenchymal cells [3]; this results in either formation of a long junctional epithelium (in case of faster migration of epithelial cells) or root resorption (in case of faster migration of connective tissue cells) [1]. Either way, the formation of a new attachment apparatus on the root surface is prevented [4].

Apart from the capacity of PTGs in space maintenance for periodontal regeneration, osteogenic capacity of titanium have been shown in experimental studies [5].

Thus, regenerative treatments are performed aiming to prevent the migration of epithelial cells and the connective tissue into the defect and maintain the space for proliferation of a specific population of cells. A new periodontal attachment is formed as such. This treatment is known as GTR [1]. The biological basis of GTR is placement of a physical barrier that prevents the migration of epithelial cells and connective tissue cells of the flap into the lesion and allows the periodontal ligament cells and mesenchymal cells to migrate on the root surface [6]. According to histological findings, GTR is the most predictable regenerative method for regeneration of bone and cementum [7]. Several materials have been used to create this physical barrier such as methyl cellulose acetate, expanded polytetrafluoroethylene (ePTFE), collagen, autogenous membranes and synthetic poly glycoside or calcium sulfate polymers [8]. These materials have a natural or synthetic origin and are divided into two groups of resorbable and non-resorbable membranes [1]. Collagen membranes are resorbable and made of type I bovine or porcine collagen. Bio-Gide belongs to this group and has a porcine origin [1].

In most cases, graft materials are placed beneath the membrane to maintain the space and to benefit from their osteoconductive or osteoinductive properties [9]. Bovine porous bone minerals (BPBMs) such as Bio-OSS® are among these materials. They are synthetized by extracting the protein from bovine bone and forming a trabecular structure of hydroxyapatite, resembling human cancelous bone. They can enhance new bone formation and are extensively used in periodontal regenerative processes [4,10].

Osteogenic properties of titanium have been documented in experimental studies. Titanium is also used for bone regeneration due to its thrombogenic properties [11,12]. Porous titanium granules (PTGs) [13,14] have been recently introduced as a bone substitute and have shown promising results in animal and clinical studies. Several studies have used PTGs for treatment of furcal defects with controversial results.

2. MATERIALS AND METHODS

An electronic search was carried out in Google Scholar and PubMed using the key words “guided tissue regeneration”, “intrabony defects”, “moderate to advanced chronic periodontitis” and “porous titanium granules”. English articles published from 2006 to 2014 were searched. The articles were then evaluated for eligibility according to the inclusion and exclusion criteria.
Inclusion criteria:
1. Studies that used PTGs in their treatment protocol.
2. Studies, which included intra-oral or extra-oral lesions as samples.
3. Human, animal and cell-culture studies.

Exclusion criteria:
1. Studies concerning stem cell engineering.
2. Studies that evaluated the fabrication of porous titanium scaffolds.

3. RESULTS

Search of the literature yielded 32 articles; based on the above-mentioned criteria, 7 were excluded and 25 remained in the study for thorough review of their full texts. Fig. 1 shows the selection process of the articles.

Table 1 shows the list of studies using PTGs in periodontal and non-periodontal treatments and summarizes the type of study, date of publication, method of application of PTGs and the outcome of treatment.

3.1 Extra-oral Applications of PTGs

A total of seven studies were found on the use of PTGs in extraoral defects; out of which, three were animal studies, two were cellular studies and two were pilot studies. Animal studies evaluated the efficacy of PTGs in hip and tibial defects and showed that membranes must be necessarily used in extensive lesions. Lamellar bone formation within the PTGs was noted [15,18]. Another study assessed the efficacy of coral as a scaffold and showed new bone formation on the surface and within the coral pores [19]. In a study, the osteogenic potential of adipose derived mesenchymal stem cells seeded on a titanium scaffold was shown using a culture medium [17]. On the other hand, calcium phosphate-coated porous titanium scaffold resulted in proliferation of mesenchymal cells [16]. A pilot study showed that PTGs were effective for the treatment of tibial fractures [20]. On the other hand, culture of femoral cells on a PTG scaffold resulted in incorporation of bone into the PTGs [13].

![Fig. 1. Literature search flow chart](image-url)
| Author                  | Type of study | Date of publication | Method of application                                                                 | Objective of study                                                                 | Results                                                                 |
|-------------------------|---------------|---------------------|---------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|------------------------------------------------------------------------|
| Delgado-Ruiz et al. [15]| Animal        | 2014                | Critical size defect in rabbit tibia                                                   | Effect of PTGs with/without membrane                                               | Membranes must be necessarily used in extensive lesions.               |
| García-Gareta et al. [16]| Cellular     | 2014                | Calcium phosphate coated porous titanium scaffold                                      | Total joint arthroplasty                                                           | This scaffold can enhance the proliferation of mesenchymal cells.      |
| Dahl et al. [17]        | Cellular      | 2013                | Application of adipose-derived mesenchymal stem cells on TiO2                          | Assessment in the culture medium                                                   | Adipose-derived mesenchymal stem cells on a titanium scaffold have osteogenic potential. |
| Turner et al. [18]      | Animal        | 2007                | Bone formation within PTGs in hip fixation                                             | Histological assessment                                                            | Lamellar bone formation within PTGs                                   |
| Xi et al. [19]          | Animal        | 2006                | Assessment of the role of coral as a scaffold                                         | Histological assessment                                                            | New bone formation on the surface and in coral pores                  |
| Jónsson and Mjoberg [20]| Pilot study   | 2009                | PTGs in treatment of tibial fractures                                                  | Clinical and radiographic assessment                                                | Effective role of PTGs in treatment of tibial fractures                |
| Alffram et al. [13]     | Pilot study   | 2007                | Culture of femoral cells in PTGs scaffold                                              | Histological and tomographic assessment                                             | Incorporation of bone and PTGs                                       |
| Rubshtein et al. [21]   | Animal        | 2014                | Assessment of bone fill in different size pores in titanium implants in the tibia and femur heads | Microscopical assessment                                                           | Functional bone formation in interstitial spaces among granules and peri-implant areas |
| Babiker et al. [22]     | Animal        | 2013                | Bilateral application in the femur head                                               | Efficacy of demineralized bone matrix alone or with cancelous bone or allograft in stabilizing porous titanium coated implant | Using a combination of demineralized bone matrix and cancelous bone can be an alternative to allografts. |
| Mijiritsky et al. [23]  | Human         | 2013                | Application of PTGs in treatment of peri-implantitis                                    | Clinical and radiographic assessment                                                | Durability of PTGs in peri-implantitis lesions                         |
| Wohlfahrt et al. [24]   | Clinical trial| 2014                | PTGs for treatment of peri-implantitis                                                  | Assessment of bone markers in                                                       | Efficacy of PTGs for decreasing                                       |
| Author                  | Type of study | Date of publication | Method of application | Objective of study | Results                                                                 |
|------------------------|---------------|---------------------|-----------------------|--------------------|------------------------------------------------------------------------|
| Wohlfahrt et al. [25]  | Animal        | 2010                | PTGs for treatment of peri-implant bone defects | Peri-implant sulcus fluid | Bone markers in peri-implant sulcus fluid PTGs are osteoconductive. |
| Wohlfahrt et al. [26]  | Clinical trial| 2012                | Assessment of the role of PTGs in peri-implant lesions compared to treatment without the application of bone substitutes | Clinical and radiographic assessment | Superior radiographic results and similar clinical results in treatment with/without PTGs |
| Thor [27]              | Case series   | 2013                | Assessment of peri-implant regeneration PTGs in treatment of peri-implant bone defects | Clinical and radiographic assessment | PTGs are osteoconductive. |
| Wohlfahrt et al. [28]  | Case report   | 2011                | Comparison of the role of PTG and Bio-Oss® in extraction sockets | Histological assessment of buccal plate resorption | PTGs is in close contact with the newly formed bone. It can effectively fill the bony defects when applied with membrane Promising role of PTGs compared to Bio-Oss® |
| Tavakoli et al. [29]   | Animal        | 2012                | Assessment of healing of an extraction socket with PTGs | Histological and histomorphometric assessments | |
| Bashara et al. [30]    | Animal        | 2012                | Comparison of the role of PTGs and hydroxyapatite for sinus floor augmentation | Histological and micro-CT assessments | Three-dimensional stability of both materials for sinus floor augmentation prior to implant placement |
| Verket et al. [31]     | Animal        | 2014                | Assessment of the role of PTGs in extraction sockets prior to implant placement | Histological and micro-CT assessments | PTGs can be applied in the extraction sockets prior to implant placement |
| Lambert et al. [32]    | Animal        | 2013                | Comparison of PTGs and hydroxyapatite for sinus floor augmentation | Histological and micro-CT assessments | Three-dimensional stability of both materials for sinus floor augmentation prior to implant placement |
| Verket et al. [33]     | Human         | 2013                | Role of PTGs in sinus floor augmentation | Histological and tomographic assessment | Osteoconductive role of titanium granules Need for further investigations due to |
| Bystedt et al. [14]    | Pilot study   | 2009                | Role of PTGs in sinus floor augmentation | Clinical assessment | |
3.2 Porous Titanium Granules in Implantology

The search yielded eight studies including three animal studies, two clinical trials and three human studies in this respect. Migration of osteoblasts on the implant surface is a prerequisite for healing of peri-implant tissues. Studies have reported that blood cell reactions are influenced by factors such as implant surface characteristics, thickness of oxide layer, chemical composition and surface roughness [25]. An animal study microscopically assessed the application of titanium granules and showed the formation of functional bone in the interstitial spaces among granules and around implants with 40% porosity. The newly formed bone was mature and contained blood vessels [21].

An animal study evaluated the efficacy of demineralized bone matrix (DBM) alone or combined with cancellous bone or allografts in stabilizing porous coated titanium implants and showed that combined use of DBM and cancellous bone was comparable with allografts in terms of mechanical properties [22]. Porous titanium granules and White PTGs (WPTGs) were compared in terms of efficacy for treatment of bone defects around implants and the results showed that PTGs and White PTGs were osteoconductive for the peri-implant bone without interfering with the process of osseointegration. Assessment of the peri-implant sulcus fluid enzymes showed less inflammation with WPTGs and increased expression of collagen mRNA in this group [25]. A case report also showed peri-implant regeneration using PTGs as an osteoconductive material [27]. A human study showed the biocompatibility of PTGs in treatment of peri-implant lesions clinically and radiographically [23]. A clinical trial on the role of PTGs in treatment of peri-implant lesions (compared to treatment with no material) demonstrated change in the percentage of radiographic bone fill in the PTG group. But the clinical results were equal in the two groups. Moreover, the results did not necessarily indicate re-osseointegration of PTGs with implants [26]. A clinical trial evaluated the efficacy of PTGs for treatment of peri-implant bone defects and assessed their effect on bone markers in peri-implant sulcus fluid (PISF). The results showed reductions in bone markers of PISF such as adiponectin, leptin, osteoprotegerin (OPG), interleukin-1 (IL1) and matrix metalloproteinase-8 (MMP8). A positive correlation was also reported...
between the reduction of IL1, MMP8, insulin and decreased probing depth due to the application of PTGs [24]. A case report on treatment of peri-implant bone defects indicated close contact of PTGs with the newly formed bone on histological and micro-CT assessments [28].

3.3 Porous Titanium Granules for Healing of Extraction Sockets

Three studies were found on the application of PTGs for extraction socket healing, which were all animal studies. Studies showed that although the application of biomaterials did not prevent resorption of buccal cortex, it optimally preserved the ridge profile [30]. An animal study assessed the healing of extraction sockets using PTGs and membrane, PTGs alone and no treatment. Histological and histomorphometric assessments showed that in the PTGs and membrane group, the total amount of regenerated bone was significantly higher than that in the other two groups [29]. Another animal study histologically compared the efficacy of PTGs and BioOss® for preserving the buccal wall of the extraction socket and showed no significant difference in the results. Also, PTGs showed a promising role compared to Bio-Oss® [30]. Another animal study assessed implant osseointegration in a tooth socket maintained with PTGs before implant placement and indicated the applicability of PTGs in the extraction sockets prior to the placement of implants [31].

3.4 Porous Titanium Granules for Sinus Floor Augmentation

Search of the literature yielded five studies including one animal and four human studies in this regard. Shorter implants had a lower survival rate in the posterior maxilla and the survival rate was 93.04% for 12 mm and 88.09% for 8mm implants [14]. An animal study compared the efficacy of PTGs and bovine hydroxyapatite for sinus floor augmentation using histological and micro CT assessments and indicated the three dimensional stability of both materials for sinus floor augmentation prior to implant placement as well as ideal bone formation with adequate quality and stiffness [32].

A human study assessed bone formation in pores of PTGs in sinus floor augmentation using histological analysis and tomography and showed that the newly formed bone was mainly woven and had a close contact with titanium granules, showing their osteoconductivity [33]. A pilot study evaluated the role of PTGs in sinus floor augmentation prior to clinical placement of implants. Due to controversial results, further investigations were requested for assessment of safety and stability of materials in the second phase [14].

Another pilot study compared PTGs and bovine bone in sinus floor augmentation histologically and three-dimensionally and revealed that PTGs and Bio-Oss® were comparable in terms of efficacy for sinus floor augmentation. Also, they showed that PTGs, in contrast to Bio-Oss®, remained for a longer period of time [34].

A human study evaluated the efficacy of PTGs in sinus floor augmentation. The results indicated their optimal efficacy [35].

3.5 Porous Titanium Granules for Treatment of Furcal Lesions

Search of the literature yielded two studies including one animal and one human study. Morphology of class II furcal defects allows their proper regeneration. Several studies have evaluated the efficacy of different materials for treatment of these lesions [36]. An animal study compared PTGs and deproteinized bovine bone for treatment of class II furcal defects using histological analysis and tomography and showed that PTGs significantly enhanced buccopalatal bone formation. Also, their application was safe adjacent to roots as they did not lead to root resorption. Both newly formed vascularized woven bone and mature lamellar bone have been reported in close contact with PTGs [36].

In a human study, PTGs were used for treatment of class II furcal lesions in the mandible. Assessment of the clinical and radiographic parameters showed that application of PTGs was safe next to roots, but it did not result in any change in clinical parameters [37].

Table 1 summarizes the studies on the application of PTGs in medicine and dentistry. Porous titanium granules have shown positive results in enhancing the outcome of treatment in medicine; most of these studies have been conducted using culture media or animal models [15-19].

Regarding the application of PTGs in dentistry, most studies have been conducted on animal and human models. PTGs have been used next
Porous titanium granules are believed to be osteoconductive and new bone is formed within these granules [21,25]. Also, their application is safe next to roots as root resorption was not reported [36]. They do not interfere with the normal healing process of extraction sockets [29]. Also, they can be effectively used for sinus floor augmentation prior to implant placement [32].

4. DISCUSSION

Porous titanium granules have shown positive results in bone augmentation. Even though these results are promising, the studies are heterogeneous and mostly limited to case reports, animal studies and experimental studies.

When PTGs were compared to Demineralized Bovine bone material, more new bone formation was seen in the PTGs group. It is assumed that the three-dimensional structure of the PTGs resembles the trabecular bone and the large surface provided from the porous design of PTGs results in more bone formation [28]. On the other hand, the surface properties of titanium may activate the coagulation system and the release of growth factors. More platelet-derived growth factor (PDGF) was detected in blood in contact with titanium. These growth factors are essential in the process of bone healing and regeneration. Thus a wide surface of titanium in contact with blood may result in more new bone formation [25].

Overall the evidence suggests the titanium scaffolds as osteoinductive and osteoconductive material which draws attention to it for the purpose of bone augmentation [12].

As titanium has a better contact with marginal bone, it preserves the marginal bone level in periodontal defects [30]. This is promising to periodontal regeneration as PTGs provide three major advantages in regeneration which is essential in periodontal defects, space maintenance, long-term stability and integration to bone.

Long-term controlled trials with large sample sizes are lacking to compare the outcomes of PTGs with previously proved materials and document the long-term results. Measurement methods must be standardized and periodontal clinical parameters as well as patient-related outcomes such as patient satisfaction should be assessed. The long-term reaction of the body to these particles should be assessed, as in contrast to other materials, PTGs tend to remain at the site with no significant alteration over time.

5. CONCLUSION

In general, it can be stated that PTGs have many applications in periodontal procedures due to their space maintaining capability, long-term substantivity, not requiring a membrane and biocompatibility in different tissues. Also, since they can be applied without a membrane, they are an affordable alternative to more expensive materials or can be used as an adjunct to other bone substitutes. Regarding these advantages, long-term randomized controlled trials in the future are suggested to further elucidate this topic.

CONSENT

It is not applicable.

ETHICAL APPROVAL

It is not applicable.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Villar CC, Cochran DL. Regeneration of periodontal tissues: Guided tissue regeneration. Dental Clinics of North America. 2010;54(1):73-92.
2. Caton JG, Greenstein G. Factors related to periodontal regeneration. Periodontology 2000. 1993;1(1):9-15.
3. Listgarten MA, Rosenberg MM. Histological study of repair following new attachment procedures in human periodontal lesions. Journal of periodontology. 1979;50(7):333-44.
4. Nyman S, Karring T, Lindhe J, Planten S. Healing following implantation of periodontitis-affected roots into gingival connective tissue. Journal of Clinical Periodontology. 1980;7(5):394-401.
5. Hong J, Andersson J, Ekdahl KN, Elgue G, Axen N, Larsson R, et al. Titanium is a highly thrombogenic biomaterial: Possible implications for osteogenesis. Thrombosis and Haemostasis. 1999;82(1):58-64.
6. Gottlow J, Nyman S, Karring T, Lindhe J. New attachment formation as the result of controlled tissue regeneration. Journal of Clinical Periodontology. 1984;11(8):494-503.

7. Venezia E, Goldstein M, Boyan BD, Schwartz Z. The use of enamel matrix derivative in the treatment of periodontal defects: A literature review and meta-analysis. Critical Reviews in Oral Biology and Medicine: an Official Publication of the American Association of Oral Biologists. 2004;15(6):382-402.

8. Kwan SK, Lekovic V, Camargo PM, Klokkevold PR, Kenney EB, Nedic M, et al. The use of autogenous periosteal grafts as barriers for the treatment of intrabony defects in humans. Journal of Periodontology. 1998;69(11):1203-9.

9. Carranza FA, Newman MG. Carranza's clinical periodontology: Elsevier health sciences; 2006.

10. Stavropoulos A, Karring T. Guided tissue regeneration combined with a demineralized bovine bone mineral (Bio-Oss) in the treatment of intrabony periodontal defects: 6-year results from a randomized-controlled clinical trial. Journal of Clinical Periodontology. 2010;37(2):200-10.

11. Gruber R, Varga F, Fischer MB, Watzek G. Platelets stimulate proliferation of bone cells: involvement of platelet-derived growth factor, microparticles and membranes. Clinical Oral Implants Research. 2002;13(5):529-35.

12. Thor A, Rasmusson L, Wennerberg A, Thomsen P, Hirsch JM, Nilsson B, et al. The role of whole blood in thrombin generation in contact with various titanium surfaces. Biomaterials. 2007;28(6):966-74.

13. Alffram PA, Bruce L, Bjursten LM, Urban RM, Andersson GB. Implantation of the femoral stem into a bed of titanium granules using vibration: A pilot study of a new method for prosthetic fixation in 5 patients followed for up to 15 years. Upsala Journal of Medical Sciences. 2007;112(2):183-9.

14. Bystedt H, Rasmusson L. Porous titanium granules used as osteoconductive material for sinus floor augmentation: A clinical pilot study. Clin Implant Dent Relat Res. 2009;11(2):101-5.

15. Delgado-Ruiz RA, Calvo-Guirado JL, Abboud M, Ramirez-Fernandez MP, Mate-Sanchez JE, Negri B, et al. Porous titanium granules in critical size defects of rabbit tibia with or without membranes. International Journal of Oral Science. 2014;6(2):105-10.
radiographic results in humans. British Dental Journal. 2013;214(5):E13.
24. Wohlfahrt JC, Aass AM, Granfeldt F, Lyngstadaas SP, Reseland JE. Sulcus fluid bone marker levels and the outcome of surgical treatment of peri-implantitis. Journal of Clinical Periodontology. 2014;41(4):424-31.
25. Wohlfahrt JC, Monjo M, Ronold HJ, Aass AM, Ellingsen JE, Lyngstadaas SP. Porous titanium granules promote bone healing and growth in rabbit tibia peri-implant osseous defects. Clinical Oral Implants Research. 2010;21(2):165-73.
26. Wohlfahrt JC, Lyngstadaas SP, Ronold HJ, Saxegaard E, Ellingsen JE, Karlsson S, et al. Porous titanium granules in the surgical treatment of peri-implant osseous defects: A randomized clinical trial. The International Journal of Oral & Maxillofacial Implants. 2012;27(2):401-10.
27. Thor A. Porous titanium granules and blood for bone regeneration around dental implants: Report of four cases and review of the literature. Case reports in dentistry. 2013;2013:410515.
28. Wohlfahrt JC, Aass AM, Ronold HJ, Lyngstadaas SP. Micro CT and human histological analysis of a peri-implant osseous defect grafted with porous titanium granules: A case report. The International Journal of Oral & Maxillofacial Implants. 2011;26(1):e9-e14.
29. Tavakoli M, Moghareabed A, Farsam T, Abbas FM, Badrian H, Khalighinejad N. Evaluation of dental socket healing after using of porous titanium granules: Histologic and histomorphometric assessment in dogs. Dental Research Journal. 2012;9(5):600-6.
30. Bashara H, Wohlfahrt JC, Polyzois I, Lyngstadaas SP, Renvert S, Ciaffey N. The effect of permanent grafting materials on the preservation of the buccal bone plate after tooth extraction: An experimental study in the dog. Clinical Oral Implants Research. 2012;23(8):911-7.
31. Verket A, Lyngstadaas SP, Ronold HJ, Wohlfahrt JC. Osseointegration of dental implants in extraction sockets preserved with porous titanium granules - An experimental study. Clinical Oral Implants Research. 2014;25(2):e100-8.
32. Lambert F, Lecloux G, Leonard A, Sourke S, Layrolle P, Rompen E. Bone regeneration using porous titanium particles versus bovine hydroxyapatite: A sinus lift study in rabbits. Clin Implant Dent Relat Res. 2013;15(3):412-26.
33. Verket A, Lyngstadaas SP, Rasmusson L, Haanaes HR, Wallstrom M, Wall G, et al. Maxillary sinus augmentation with porous titanium granules: A microcomputed tomography and histologic evaluation of human biopsy specimens. The International Journal of Oral & Maxillofacial Implants. 2013;28(3):721-8.
34. Vandeweghe S, Leconte C, Ono D, Coelho PG, Jimbo R. Comparison of histological and three-dimensional characteristics of porous titanium granules and deproteinized bovine particulate grafts used for sinus floor augmentation in humans: A pilot study. Implant Dentistry. 2013;22(4):339-43.
35. Helmut G, Steveling CM. Sinus floor augmentation using porous titanium granules A retrospective study in patients with limited residual alveolar bone. EDI. 2014;9(2):76-80.
36. Wohlfahrt JC, Aass AM, Ronold HJ, Heijl L, Haugen HJ, Lyngstadaas SP. Microcomputed tomographic and histologic analysis of animal experimental degree II furcation defects treated with porous titanium granules or deproteinized bovine bone. Journal of Periodontology. 2012;83(2):211-21.
37. Wohlfahrt JC, Lyngstadaas SP, Heijl L, Aass AM. Porous titanium granules in the treatment of mandibular Class II furcation defects: A Consecutive Case Series. Journal of Periodontology. 2012;83(1):61-9.

© 2016 Nateghi et al.; This is an Open Access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Peer-review history:
The peer review history for this paper can be accessed here:
http://sciencedomain.org/review-history/13000