CASE REPORT

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Application of modern computer-aided technologies in the production of individual bone graft: A case report

Upotreba savremenih tehnologija podržanih računarom u izradi individualnog koštanog grafta

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Abstract

Introduction. An autologous bone (bone derived from the patient himself) is considered to be a "golden standard" in the treatment of bone defects and partial atrophic alveolar ridge. However, large defects and bone losses are difficult to restore in this manner, because extraction of large amounts of autologous tissue can cause donor-site problems. Alternatively, data from computed tomographic (CT) scan can be used to shape a precise 3D homologous bone block using a computer-aided design–computer-aided manufacturing (CAD-CAM) system. **Case report.** A 63-year old male patient referred to the Clinic of Dentistry of Vojvodina in Novi Sad, because of teeth loss in the right lateral region of the lower jaw. Clinical examination revealed a pronounced resorption of the residual ridge of the lower jaw in the aforementioned region, both horizontal and vertical. After clinical examination, the patient was referred for 3D cone beam (CB)CT scan that enables visualization of bony structures and accurate measurement of dimensions of the residual alveolar ridge. Considering the large extent of bone resorption, the required ridge augmentation was more than 3 mm in height and 2 mm in width along the length of some 2 cm, thus the use of granular material was excluded. After consulting prosthodontists and engineers from the Faculty of Technical Sciences in Novi Sad we decided to fabricate an individual (custom) bovine-derived bone graft designed according to the obtained 3D CBCT scan. **Conclusion.** Application of 3D CBCT images, computer-aided systems and software in manufacturing custom bone grafts represents the most recent method of guided bone regeneration. This method substantially reduces time of recovery and carries minimum risk of postoperative complications, yet the results fully satisfy the requirements of both the patient and the therapist.

Key words:
computer-aided design; cone-beam computed tomography; bone regeneration; alveolar bone loss; patient satisfaction.

Apstrakt

Uvod. Autologna kost (kost koja potiče od samog pacijenta) smatra se zlatnim standardom u obnavljanju koštanih defekata i delimično atrofičnog alveolarnog grebena. Međutim, velike defekte i gubitke kosti teško je restaurirati na ovaj način jer uzimanje veće količine autologne kosti može stvoriti ozbiljne komplikacije na donorskim mestima. Kao alternativna metoda mogu se koristiti podaci dobijeni kompjuterizovanom tomografijom, pomoću kojih je moguće izraditi precizan 3D homologni koštani graft. **Prikaz bolesnika.** Na Kliniku za stomatologiju Vojvodine u Novom Sadu upućen je 63-godišnji muškarac zbog nedostatka zuba u donjoj vilici, bočno. Kliničkim pregledom utvrđena je izražena resorpcija ostatka grebena donje vilice u navedenom delu, kako horizontalno, tako i vertikalno. Pacijent je potom upućen na 3-dimenzijalnu kompjutersku tomografiju konusnim snopom (3D CBCT) da bi se snimila koštana struktura i tačno izmerile dimenzije preostalog alveolarnog grebena. Usled velike resorpcije kosti, bilo je potrebno uvećanje grebena više od 3 mm i šire od 2 mm duž 2 cm, zbog čega je isključena upotreba zrnastog materijala. Posle savetovanja sa prostadontistima i inženjerima sa Fakulteta tehničkih nauka, odlučeno je da se napravi individualni (po meri) graft od goveđe kosti prema modelu dobijenom 3D CBCT snimanjem. **Zaključak.** Primena 3D CBCT računarskih sistema i softvera za proizvodnju individualnih koštanih graftova predstavlja najnoviju metodu vođene koštane regeneracije. Ova metoda značajno skraćuje vreme oporavka i nosi minimalni rizik od postoperativnih komplikacija, uz potpuno zadovoljenje zahteva kako pacijenata tako i terapeuta.

Ključne reči:
kompjuterski podržan dizajn; kompjuterizovana tomografija konusnog zraka; kost, regeneracija; alveolna kost, gubitak; bolesnik, zadovoljstvo.

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Introduction

Prosthetic rehabilitation of the posterior atrophic edentulous mandible presents a common clinical problem [1–7]. Fixed implant supported prosthesis is an ideal therapeutic solution. However, this can be impeded by the deficiency in height and width of the residual alveolar bone, associated with the consequent superficial position of the inferior alveolar nerve. In these circumstances, the placement of an implant of adequate length and appropriate subsequent prosthetic rehabilitation is difficult, almost impossible [2]. The knife-edge configuration of the residual bone crest does not provide sufficient base to contain particulate grafting material. Therefore, a strong rigid graft is required to allow fixation to the recipient site and 3-dimensional (3D) stability to withstand muscular forces [8]. For all these reasons, when we require a graft in the posterior mandible, which exceeds 3 mm in either width, height or both, a bone block graft is recommended [9, 10]. An autologous bone (bone derived from the patient himself) is considered to be a "golden standard" in the treatment of bone defects and partial atrophic alveolar ridge. It exhibits excellent bioabsorption capabilities and is never rejected by the body. However, large defects and bone losses are difficult to restore in this manner, because the extraction of large amounts of autologous tissue can cause donor-site problems. Alternatively, data from a cone-beam computed tomographic (CBCT) scan can be used to shape a precise 3D homologous bone block using a computer-aided design–computer-aided manufacturing (CAD-CAM) system. In this way, the bone block can be transferred directly from its sterile packaging to the receiving site without the need to be shaped [1].

Case report

A 63-year old male patient referred to the Clinic of Dentistry of Vojvodina, Novi Sad, because of teeth loss in the right lateral region of the lower jaw. Clinical examination revealed a pronounced resorption of the residual ridge of the lower jaw in the aforementioned region, both horizontal and vertical (Figure 1). After clinical examination, the patient was referred for 3D CBCT scan that enables visualization of bony structures and accurate measurement of dimensions of the residual alveolar ridge (Figure 2).

After a thorough measurement of bony structures, 3D CBCT scan indicated that an adequate implant-prosthetic rehabilitation is impossible without prior augmentation of the residual alveolar ridge in the mandibular region. Considering the large extent of bone resorption, the required ridge augmentation was more than 3 mm in height and 2 mm in width along the length of some 2 cm, thus the use of granular material was excluded. After consulting prosthodontists and engineers from the Faculty of Technical Sciences in Novi Sad we decided to fabricate an individual (custom) bovine-derived bone graft designed according to the obtained 3D CBCT scan.

3D design of a graft model

Generating 3D model of the jaw is the first step in the graft modelling procedure. The procedure is performed according to Cone Beam CT images provided in DICOM format that enables further generation of the 3D model of patient's lower jaw. This procedure is essential since the 3D model of the lower jaw is the basis for graft modelling. The procedure also enables visual and functional inspection of the 3D graft model. The 3D model of the patient's lower jaw generated on the basis of CBCT scans made with 3D-DOCTOR software is presented in Figure 3. After generating the 3D model of the lower jaw, input parameters, such as shape and size of the graft and its position in the jaw, were defined. At this stage, the highest level of cooperation within a multidisciplinary team involving oral surgeons and engineers was accomplished to obtain a 3D graft model that would satisfy both medico-esthetic and technical and functional requirements.

Upon defining the input parameters, the 3D graft modelling procedure was performed. Since the modelling procedure involved the complex free-form surfaces, the application of conventional CAD-software for modelling of standard geometric shapes was impossible [11] and the use of specialized 3D-modelling software was suggested. The 3D model of the lower jaw was used as the basis for modelling of lower graft surface (Figure 4). In this way, an adequate con-

Fig. 1 – Intraoral image of the patient.

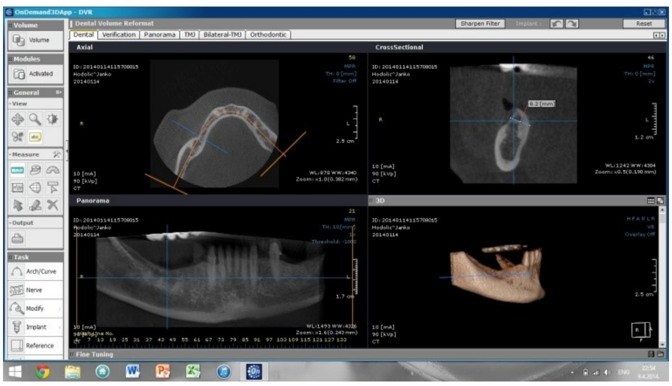

Fig. 2 – Preoperative 3D cone-beam computed tomography (CBCT).

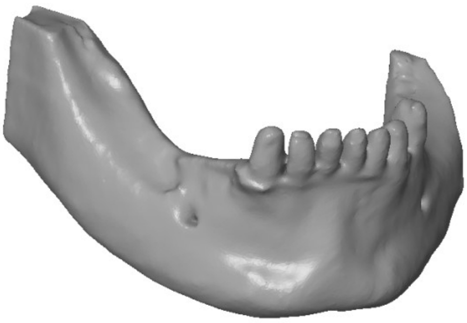

Fig. 3 – 3D model of patient's lower jaw generated according to cone-beam computed tomography (CBCT) scans.

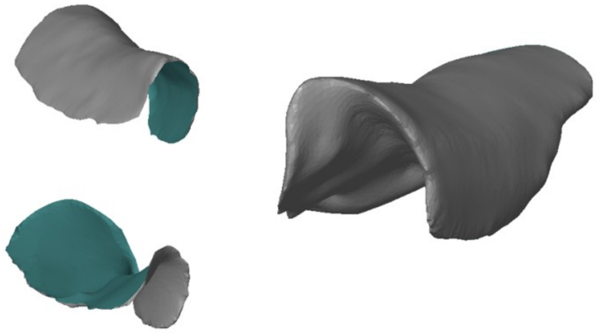

Fig. 4 – The procedure of 3D graft modelling.

formation of the bone graft was provided. Subsequently, the upper graft surface was modelled using complex-surface manipulation tools taking into consideration the shape, thickness and size of the graft. The size of the graft was determined according to the number of required implants. Finalized 3D model of the graft was saved in stereolitography (STL) file format that enables easy manipulation and data exchange between software programs.

In the next step, the 3D graft model was fitted together with the 3D model of the lower jaw and implant models using OnDemand3D computer software. During this stage, geometric characteristics of the graft were analyzed, as well as its position in the jaw in relation to the implants (Figures 5 and 6). This step also involved a multidisciplinary team composed of surgeons and engineers and encompassed the final check-up of the following parameters: cross-sections of the grafts; maximum dimensions (length, width, height); minimum graft wall thickness; negative angles of the graft; sharp edges.

The process of designing the 3D graft model was carried out taking into consideration the performance of the equipment for graft manufacturing and the minimum required cross-sectional graft thickness of 3 mm. Cross-sectional graft thickness less than 3mm would seriously disturb its mechanical properties. Reduction of mechanical properties is directly associated with the porosity of graft material. Thus, graft placement into the jaw might be compromised by potential breakage of the graft while positioning and fixing it with appropriate screws. After satisfying all virtual esthetic and functional requirements, the

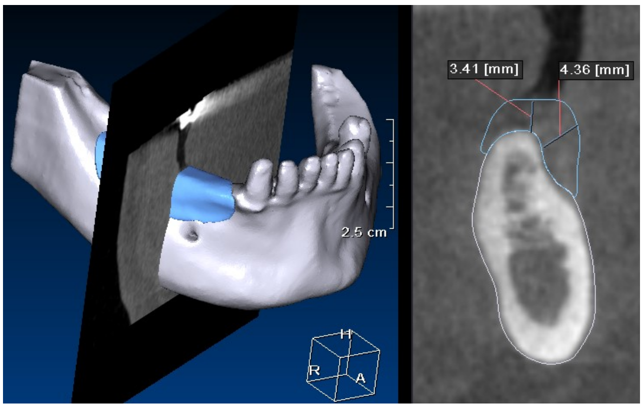

Fig. 5 – Cross-sectional view of the graft thickness obtained using OnDemand 3D software.

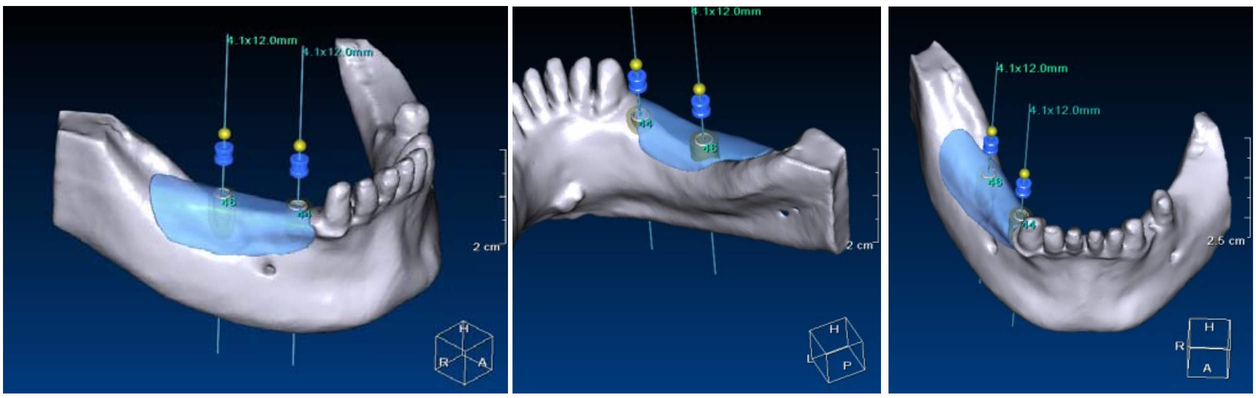

Fig. 6 – Virtual positioning of the implant and graft into the lower jaw using OnDemand 3D computer software.

graft model was manufactured along with the jaw by applying the rapid prototyping (RP) technology. 3D printing of the graft and jaw enabled oral surgeons to “hold the result”, i.e. the solid object in their hands and to analyze the physical model (Figure 7). This step represented the last inspection prior to final fabrication, which enabled identification and elimination of some potential problems that were not visible in the virtual 3D model. After completing the required modifications and corrections of the 3D model, the final version of the graft was sent for fabrication using computer numerical control (CNC) milling machine-tool. Having in mind the complex shape of the graft, the fabrication was performed using a CNC machine-tool with the 5 degrees of freedom. The graft was manufactured from a monoblock of biocompatible material of bovine origin. Upon finishing, it was sterilized using ethylene oxide. Besides the prism-shaped block as the initial shape, a variety of shapes such as plates, cylinders, rods, etc, are available for manufacturing grafts with desired shape and dimensions. Virtual planning image of the composite block used for graft fabrication is presented in Figure 8. Block dimensions were (36.7 × 14.2 × 12 mm) length × height × width with the total block volume of 6.44 cm^3.

Surgical procedure

After delivering the custom bone graft in an original sterile package, the surgical procedure was performed (Figure 9a). Under block anesthesia of the inferior alveolar nerve, the full-thickness mucoperiosteal flap was lifted to expose the residual alveolar ridge. Using a 1-mm steel micro drill, perforations in the mandibular cortex were made to enhance blood supply to the graft. Bone graft was carefully positioned and fixed using two 12 mm titanium screws (Figure 9b). With the aim of preventing proliferation of fibrous tissue and infection, the graft was covered with two bio-absorbable collagen membranes that are essential for a successful augmentation procedure (Figure 9c). To eliminate tension force and reduce pressure onto the bone graft, periosteal releasing incision was made at the base of the flap and surgical region was closed with non-resorptive surgical suture 5-0 applying the horizontal mattress stitch technique. After completing surgery, control dental panoramic tomography (OPT) radiograph was made for checking the position of bone graft (Figure 9d).

During the postoperative course, antibiotic therapy was introduced (clindamycin + metronidazole) along with cold compresses and analgesics, and the patient was instructed on an appropriate hygienic-dietary regime.

Discussion

Deficit of the residual bone required to provide optimal conditions for an ideal placement of dental implant is a common problem in daily clinical practice. In such situation, adequate bone regeneration can provide the structural support. More than 60% of the population in highly industriali-

Fig. 7 – Physical models of the lower jaw generated by the rapid prototyping RP technology.

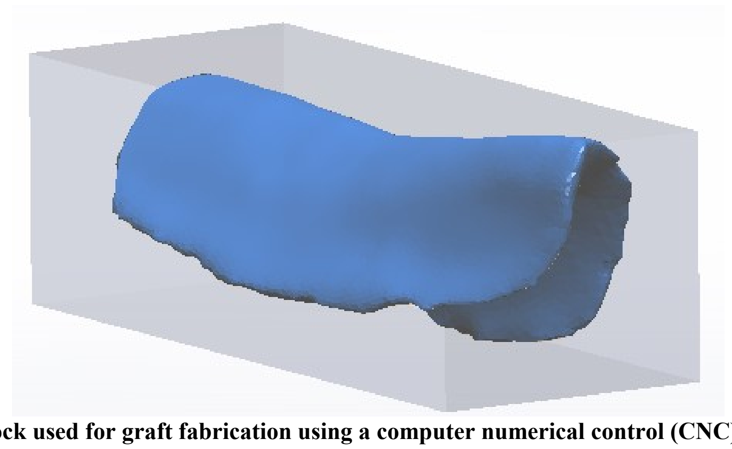

Fig. 8 – Virtual block used for graft fabrication using a computer numerical control (CNC) processing center.

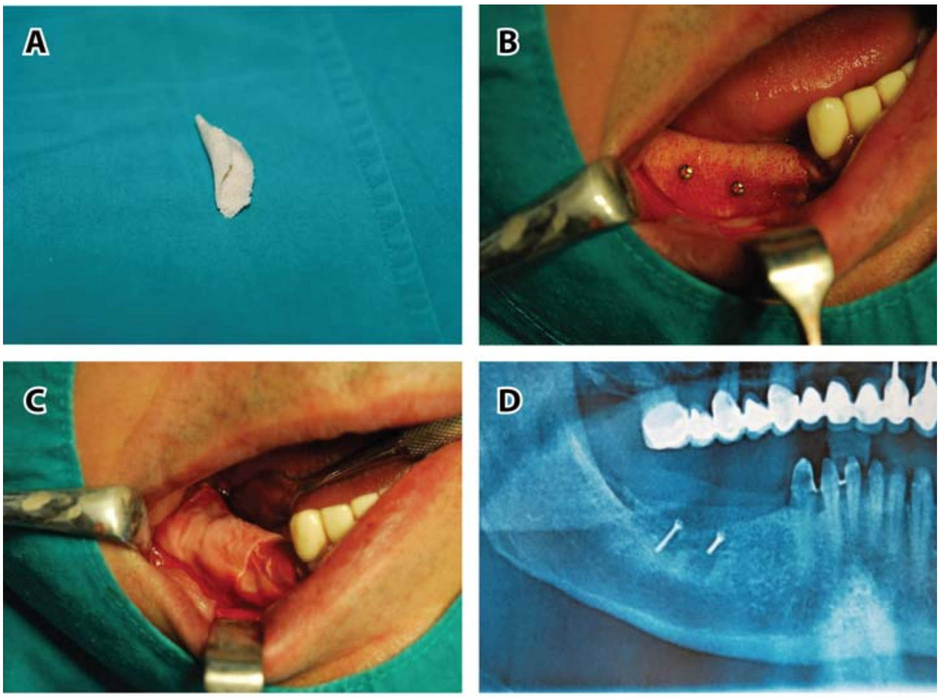

Fig. 9 – Surgical procedure step-by-step: a) custom bone graft ready for implantation; b) bone graft positioning and fixing in the lower jaw; c) graft covering with two bio-absorbable collagen membranes; d) control dental panoramic tomography radiograph showing correct graft position in the jaw.

zed countries requires implant-prosthetic rehabilitation, which results in a yearly increase of implant market for some 15% [12]. Nowadays, autologous bone grafts are considered the "golden standard" in bone regeneration and augmentation of substantial volume of the lost alveolar ridge. However, their major drawbacks include limited number of donor sites, the necessity of additional surgical procedure in a hardly accessible region of the oral cavity, need for general anesthesia, substantial trauma for the patient, as well as a prolonged postoperative recovery [13]. Thus, development and application of "artificial" custom (individual) grafts, which are characterized by relatively simple preparation, good predictability of the outcome and "comfort" for the patient himself, has been gaining increased attention. Demineralized freeze-dried allogeneic bone transplants can stimulate new bone formation and are a viable alternative to bone autograft material [14]. The custom-made grafts well matched the shape of the bone defects and could be easily implanted during surgery. This matching of the shape helped to reduce the time for the operation and contributed to the good healing of the defects [15].

The presented clinical report confirms that bone grafts could be created in the automated manner, starting from CT, and customized to each patient and for each type of clinical situation by applying modern X-ray techniques (3D CBCT) and advanced computer aided software systems. This enables diagnostic and surgical procedures, reduces time and improves the precision in adapting the graft, which is critical to its integration with the surrounding bone [16].

Conclusion

In our everyday clinical practice, we face a relatively large number of patients indicated for implant-prosthetic treatment. The loss of single or multiple teeth may result in substantial deficit of the residual alveolar ridge. Such situations require augmentation of lost bony structures in order to provide optimal conditions for dental implant placement and subsequent prosthetic rehabilitation. Application of 3D CBCT images, computer-aided systems and software in manufacturing custom bone grafts represents the most recent example of guided bone regeneration. This method substantially reduces time of recovery and carries minimum risk of postoperative complications, yet the results fully satisfy the requirements of both the patient and the therapist. The results presented in this article confirm the importance and effectiveness of computer-aided systems for 3D digitization, design and fabrication of custom bone grafts.

R E F E R E N C E S

1. *Jacotti M, Barausse C, Felice P.* Posterior atrophic mandible rehabilitation with onlay allograft created with CAD-CAM procedure: a case report. Implant Dent 2014; 23(1): 22−8.
2. *Felice P, Cannizzaro G, Checchi V, Marchetti C, Pellegrino G, Censi P,* et al. Vertical bone augmentation versus 7-mm-long implants in posterior atrophic mandibles. Results of a randomised controlled clinical trial of up to 4 months after loading. Eur J Oral Implantol 2009; 2(1): 7−20.
3. *Felice P, Pellegrino G, Checchi L, Pistilli R, Esposito M.* Vertical augmentation with interpositional blocks of anorganic bovine bone vs. 7-mm-long implants in posterior mandibles: 1-year results of a randomized clinical trial. Clin Oral Implants Res 2010; 21(12): 1394−403.
4. *Felice P, Piana L, Checchi L, Pistilli R, Pellegrino G.* Vertical ridge augmentation of the atrophic posterior mandible with a 2-stage inlay technique: a case report. Implant Dent 2012; 21(3): 190−5.
5. *Felice P, Piattelli A, Iezzi G, Degidi M, Marchetti C.* Reconstruction of an atrophied posterior mandible with the inlay technique and inorganic bovine bone block: a case report. Int J Periodontics Restorative Dent 2010; 30(6): 583−91.
6. *Esposito M, Cannizarro G, Soardi E, Pellegrino G, Pistilli R, Felice P.* A 3-year post-loading report of a randomised controlled trial on the rehabilitation of posterior atrophic mandibles: short implants or longer implants in vertically augmented bone. Eur J Oral Implantol 2011; 4(4): 301−11.
7. *Esposito M, Pellegrino G, Pistilli R, Felice P.* Rehabilitation of postrior atrophic edentulous jaws: prostheses supported by 5 mm short implants or by longer implants in augmented bone? One-year results from a pilot randomised clinical trial. Eur J Oral Implantol 2011; 4(1): 21−30.
8. *Chiapasco M, Abati S, Romeo E, Vogel G.* Clinical outcome of autogenous bone blocks or guided bone regeneration with e-PTFE membranes for the reconstruction of narrow edentulous ridges. Clin Oral Implants Res 1999; 10(4): 278−88.
9. *Schwartz-Arad D, Levin L.* Intraoral autogenous block onlay bone grafting for extensive reconstruction of atrophic maxillary alveolar ridges. J Periodontol 2005; 76(4): 636−41.
10. *Pikos MA.* Block autografts for localized ridge augmentation: Part II. The posterior mandible. Implant Dent 2000; 9(1): 67−75.
11. *Budak I, Soković M, Barišić B.* Accuracy improvement of point data reduction with sampling-based methods by Fuzzy logic-based decision-making. Measurement 2011; 44(6): 1188−200.
12. *Petersson K, Pamenius M, Eliasson A, Narby B, Holender F, Palmqvist S,* et al. 20-year follow-up of patients receiving high-cost dental care within the Swedish Dental Insurance System: 1977-1978 to 1998-2000. Swed Dent J 2006; 30(2): 77−86.
13. *Giannnoudis PV, Dinopoulos H, Tsiridis E.* Bone substitutes: an update. Injury 2005; 36(3): 20−7.
14. *Fretwurst T, Spanou A, Nelson K, Wein M, Steinberg T, Stricker A.* Comparison of four different allogeneic bone grafts for alveolar ridge reconstruction: a preliminary histologic and biochemical analysis. Oral Surg Oral Med Oral Pathol Oral Radiol 2014; 118(4): 424−31.
15. *Figliuzzi M, Mangano FG, Fortunato L, de Fazio R, Macchi A, Iezzi G,* et al. Vertical ridge augmentation of the atrophic posterior mandible with custom-made, computer-aided design/computer-aided manufacturing porous hydroxyapatite scaffolds. J Craniofac Surg 2013; 24(3): 856−9.
16. *Macchi A, Mangano C, Inversini M, Norcini A, Binaghi E.* Scaffolds individualizzati (Custom Made) nella rigenerazione ossea dei mascellari. Implantologia Orale 2006; 4: 7−15.

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