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 grafa

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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 donor-site of 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 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 prostodontists and engineers from the Faculty of Technical Sciences, University of 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 minimal 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 uziimanje veće količine autologne kosti može stvoriti ozbiljne komplikacije na donorskim mestima. Kao alternativa metoda mogu se koristiti podaci dobiveni kompjuterizovanom tomografijom, pomoću kojih je moguće izraditi precizan 3D homologni koštani grafit. Prikaz bolesnika. Na Kliniku za stomatologiju Vojvodine u Novom Sadu upućen je 63-godišnji muškarac zbog nedostatka zuba u donjoj vilici, boćno. Kliničkijim pregledom utvrđena je izražena resorpcija ostataka grebena donje vilice u navedenom delu, kako horizontalno, tako i vertikalno. Pacijent je potom upućen na 3-dimenzionalnu 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) grafit od bovina izradić 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 minimal risk of postoperative complications, yet the results fully satisfy the requirements of both the patient and the therapist.

Ključne reči: kompjuterizovana kompjuterska tomografija konusnog zraka; kost; regeneracija; alveolna kost; gubitak; bolesnik, zadovoljstvo.
Introduction

Prosthetic rehabilitation of the posterior atrophic edentulous mandible presents a common clinical problem 1-7. Fixed implant supported prosthetic 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 medicesthetic 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-
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 stereolithography (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 3 mm 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
A 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 cm³.

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-resorbptive 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 industrialized...
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.

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.

**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.
REFERENCES


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