Interactive 3D imaging technologies: application in advanced methods of jaw bone reconstruction using stem cells/pre-osteoblasts in oral surgery

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Abstract

Cone beam computed tomography has created a specific revolution in maxillofacial imaging, facilitating the transition of diagnosis from 2D to 3D, and expanded the role of imaging from diagnosis to the possibility of actual planning. There are many varieties of cone beam computed tomography-related software available, from basic DICOM viewers to very advanced planning modules, such as InVivo Anatomage, and SimPlant (Materialise Dental). Through the use of these programs scans can be processed into a three-dimensional high-quality simulation which enables planning of the overall treatment. In this article methods of visualization are demonstrated and compared, in the example of 2 cases of reconstruction of advanced jaw bone defects using tissue engineering. Advanced imaging methods allow one to plan a miniinvasive treatment, including assessment of the bone defect's shape and localization, planning a surgical approach and individual graft preparation.

Key words: *three-dimensional imaging, dental implants, regenerative medicine.*

Introduction

The inventor of digital radiography, Dr Francis Mouyen, used to say that a dentist without radiological diagnosis is like a luxury car driver with his eyes covered [1]. At present, it is difficult to imagine comprehensive treatment planning without considering radiological diagnosis [2–8]. Single dental X-rays, panoramic images and cephalometric radiographs until recently represented the standard of treatment planning in the maxillofacial area. The main disadvantage of these images is their 2-dimensionality. Cone beam computed tomography (CBCT), also known as digital volumetric tomography, was developed in the late 1990s and has proved to be a useful tool in many aspects of oral and maxillofacial surgery as well as in implant dentistry [3]. Due to the fact that it is a 3-dimensional examination it excludes the problem of overlapping anatomical structures, as in the case of conventional 2-dimensional radiography. During the examination the arm rotates around the patient's head by performing a series of projections. Data obtained during one rotation of the device in less than 1 min allow one to obtain images that formerly required the implementation of a number of X-rays. Detectors record images of various parts resulting in a 3-dimensional image that can be processed in an infinite number of ways. Dental cone beam scans offer invaluable information about maxillofacial structures and are currently used in all fields of dentistry including endodontics and orthodontics. Currently produced CBCT scanners seek to eliminate the radiation dose absorbed by the patient during the test.

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Cone beam computed tomography has created a specific revolution in maxillofacial imaging, facilitating the transition of dental diagnosis from 2D to 3D, and expanded the role of imaging from diagnosis to the possibility of actual planning. There are many varieties of CBCT related software available, from basic DICOM viewers to very advanced planning modules, such as InVivo Anatomage, and SimPlant (Materialise Dental). Through the use of these programs scans could be processed into 3-dimensional high-quality simulation, which enables one to plan the overall treatment.

Aim

In this article methods of visualization are demonstrated and compared, in the example of advanced cases of jaw bone defect reconstruction using tissue engineering.

Material and methods

Three-dimensional radiological diagnosis was performed in the Department of Oral Surgery, Medical University of Warsaw among 30 patients treated due to large jaw bone defects of different etiology. Interactive visualization technologies were used during planning and monitoring a novel method of bone defect treatment consisting of an advanced method of tissue engineering (allogenic bone blocks infiltrated with autologous pre-osteoblasts proliferated and differentiated *in vitro* (4-week culture) from stem cells taken from the bone marrow aspiration biopsy). The procedure was applied in generally healthy patients (detailed inclusion/exclusion criteria). In each case CBCT (Gendex) was performed to visualize the shape and length of the bone defect in order to achieve precise treatment planning and preparation of an adequate bone graft by using piezosurgery (Mectron Piezosurgery Touch) and rotation saws (W&H). Allogenic bone blocks were prepared according to the standards at the Central Tissue Bank, MUW. The CBCT data were subsequently processed through InVivo Anatomage and SimPlant (Materialise Dental) software. In the first stage the data obtained from classical CBCT, InVivo Dental Anatomage and SimPlant (Materialise Dental) were used for preliminary diagnosis of bone defects, planning of the complex treatment and selecting the surgical approach. At a later phase of treatment scans and 3D visualizations enabled control of graft remodeling, its incorporation to the recipient bone site and assessment of early mineralization sites at the present scaffold. In cases requiring tooth replacement advanced 3-dimensional imaging software enabled simulation of dental implant installation. A description of the procedures is presented below in the example of two different bone defects.

Congenital bone defect – deficient quantity of bone accompanying congenital lack of lower central incisors

Congenital absence of upper lateral incisors was recently compensated orthodontically, when the place for implants in the midline of the lower jaw was prepared. The CBCT scans (Gendex) revealed insufficient residual bone volume in the area of lower central incisors for implant placement (Photo 1). For more detailed assessment of quality and quantity of the alveolar bone a 3D visualization was done using InVivo Anatomage (Photo 2) and SimPlant (Materialise Dental) software (Photo 3). Based on a detailed analysis of the images bone augmentation was planned before the installation of dental implants. The congenital bone defect was filled with the graft (allogenic bone block + 40 × 10^6 pre-osteoblasts) and stabilized by 2 micro-screws (Medartis). Control CBCT was performed to visualize the graft (Photo 4). For better imaging, scans were converted and 3D reconstructions were performed (Photos 5, 6). Early implant placement was planned using InVivo and SimPlant programs (Photos 7, 8).

Post-cystectomy bone defect – periapical cyst located in the anterior part of the maxilla

The CBCT (Gendex) scans showed an osteolytic defect extending from the upper right central incisor to the upper left canine through the width of the maxilla from the buccal to the palatal site (Photo 9). The surgical bone defect treatment was planned using the methodology described above. The cyst was completely removed. Root resection of left upper incisors was performed. The bone defect was filled with allogenic bone block, which was ex tempore saturated with autologic preosteoblasts and then fixed with a miniplate for osteosynthesis (Medartis). Control CBCT was performed to visualize the graft. For more accurate imaging scans were converted and 3D reconstructions were performed (Photos 10, 11).

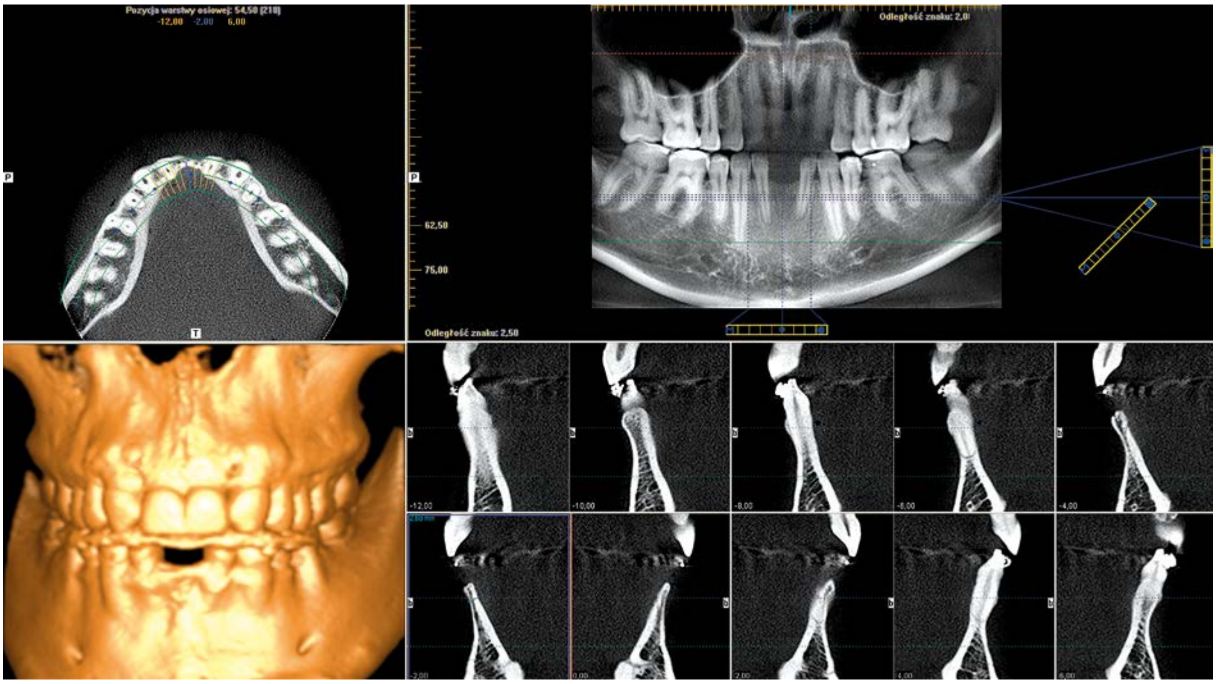

Photo 1. Cone beam coputed tomography planning. Insufficent residual bone volume in the area of lower central incisors for implant placement (congenital bone defect)

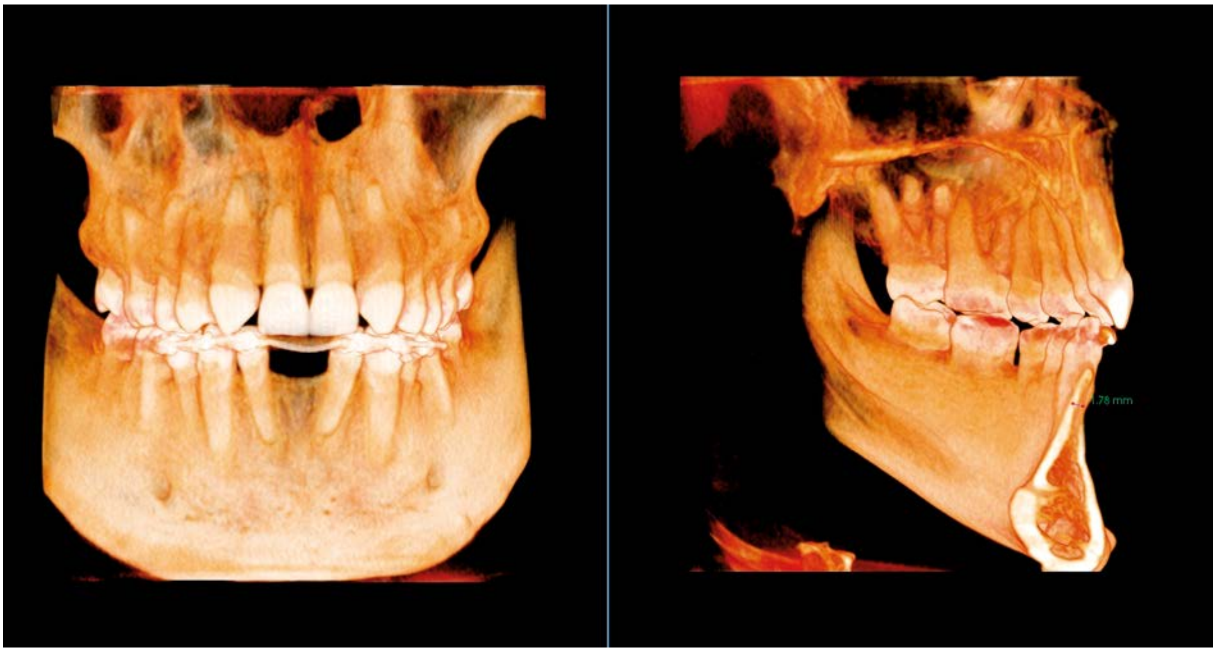

Photo 2. InVivo Anatomage visualization of congenital bone defect in mandible. Alveolar ridge width: 1.78 mm

Results

Application of 3-dimensional imaging technologies (InVivo Anatomage, SimPlant (Materialise) have enabled wide and precise diagnosis, reducing operative time, possibility of monitoring the patients treated using advanced methods of tissue engineering, early implant treatment planning and consequently higher operator self-confidence and greater safety for the patient.

Photo 3. Simplant visualization of congenital bone defect in mandible

Discussion

Implant treatment has become increasingly popular and accessible [9–12]. One of the basic conditions for successful implant rehabilitation is an adequate alveolar bone base. In practice, frequently observed deficient bone quantity becomes a challenge for the surgeon. The most precise method allowing an accurate assessment of osseous conditions is 3-dimensional computed tomography. The examination enables the detection of various bone defects, such as age-related atrophies, pathological lesions, injuries, congenital disorders and systemic diseases. In many cases, these defects could not be detected or adequately diagnosed on conventional 2D radiographs. The alveolar bone quantity influ-

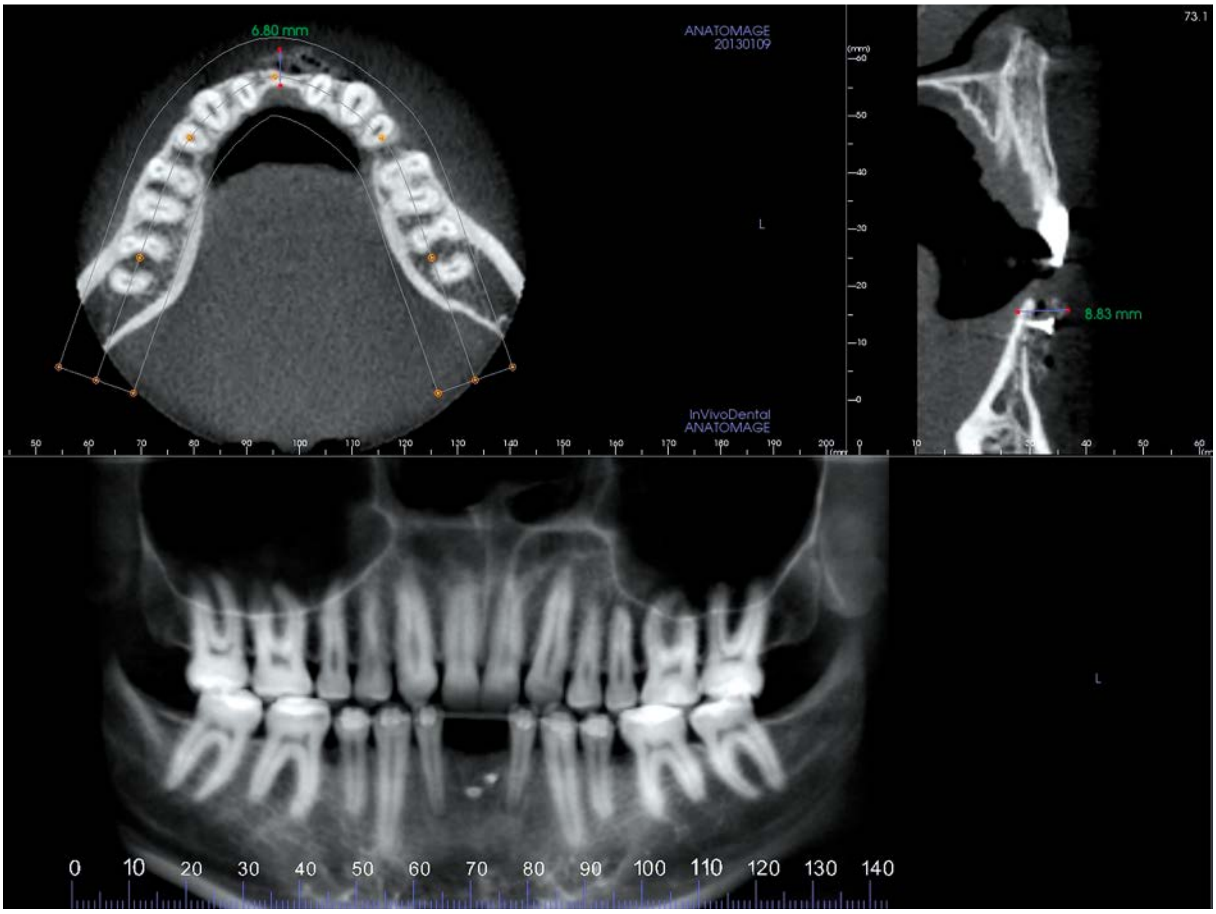

Photo 4. Post-surgery CBCT. Alveolar ridge width after augmentation: 8.83 mm

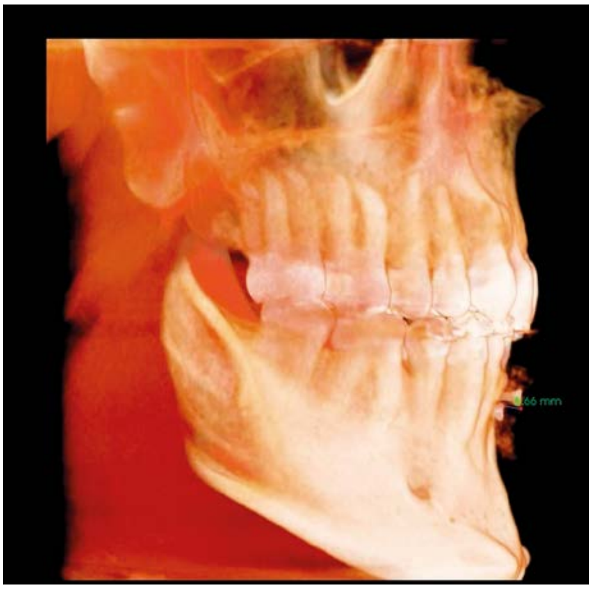

Photo 5. Post-surgery visualization of augmentation of bone defect in mandible using InVivo Anatomage software

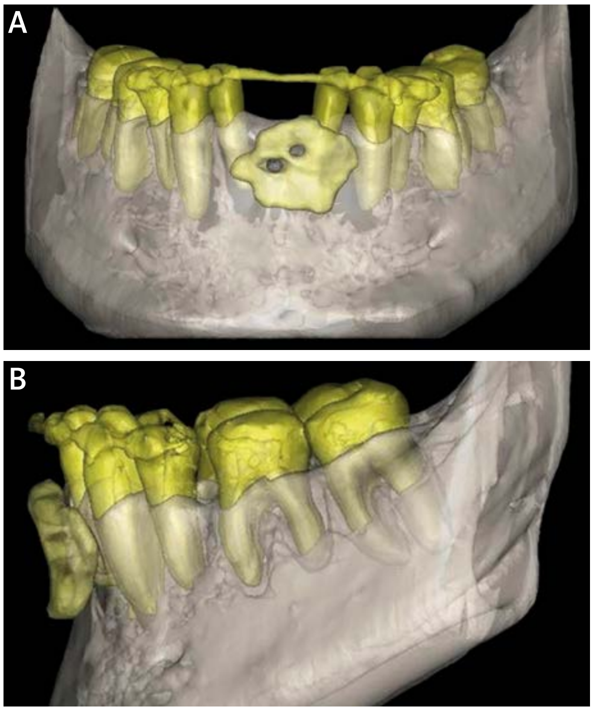

Photo 6. Post-surgery visualization of augmentation of bone defect in mandible using Simplant software

Photo 7. Visualization of implants placement in the mandible using InVivo Anatomage software

ences a number of factors in the overall implant treatment plan: bone augmentation, implant type, implant length, and implant installation angle [9]. Assessment of the quality of the bone comprises the thickness of cortical bone and characteristics of trabecular bones, which is an important factor because it contributes to implant stability [13–19]. Modern 3-dimensional visualization software allows in addition spatial evaluation of maxillofacial structures and virtual installation of dental implants. Such a pre-surgical procedure allows for the later noninvasive installation of dental implants in the appropriate place without damaging the anatomical structures. Furthermore, 3D visualization is a useful tool to explain and illustrate the treatment plan to the patient. A visible image of the planned rehabilitation raises the patient's confidence and benefits the patient-doctor cooperation [20, 21].

InVivo Anatomage and SimPlant (Materialise) programs are useful tools in monitoring patients after treatment of jaw bone defects using tissue engineering techniques. In the presented method allogenic bone blocks are highly visible on the controlled scans and exhibit characteristics of incorporation into residual bone. InVivo Dental Anatomage is easy to use and quickly visualizes transparent hard tissue, detailed bone profile, soft tissues, sinus anatomy, airways and skin profiles. The program offers fast implant planning, after which a dynamic simulation of the virtual surgery could be played in front of the patient. Additionally, these simulations can be captured as videos and saved for records or used at subsequent appointments.

The SimPlant software allows a precise assessment of the patient anatomical structures and allows one to simulate implant placement and bone

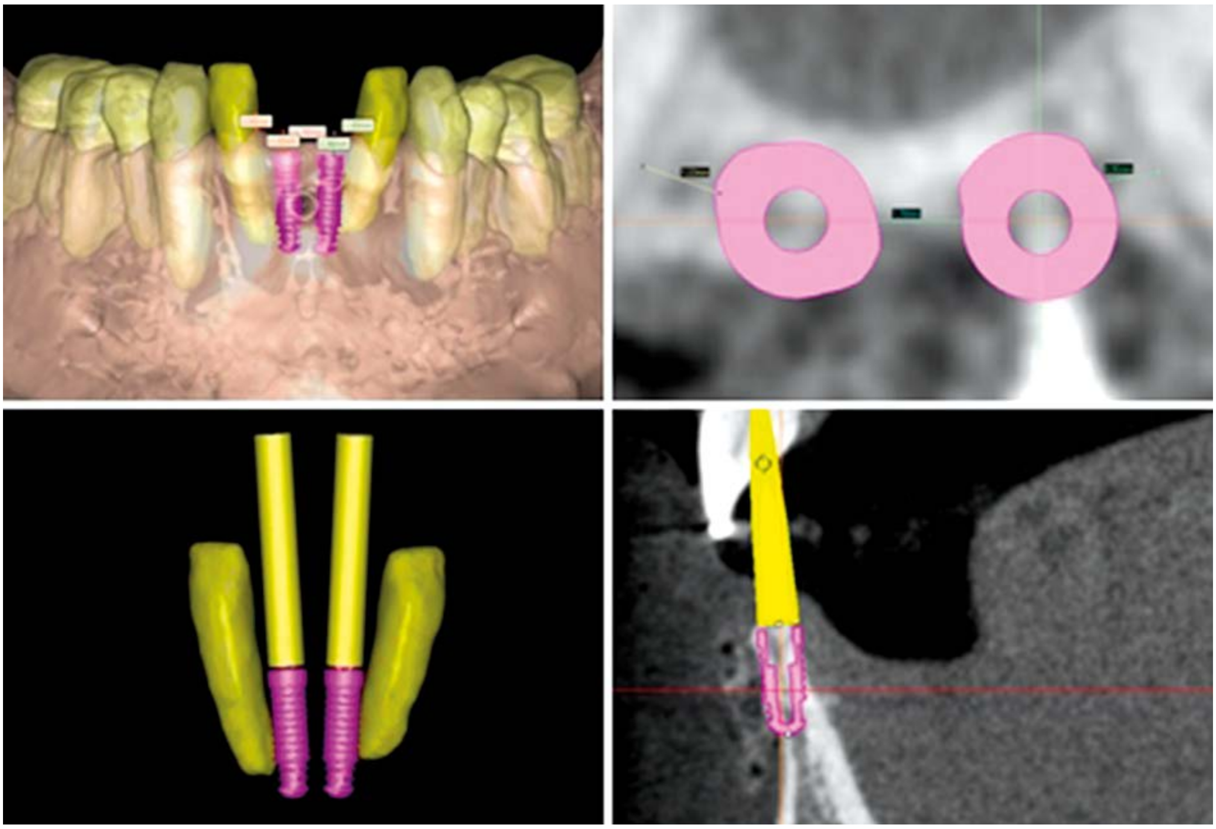

Photo 8. Visualization of implants placement in the mandible using Simplant software

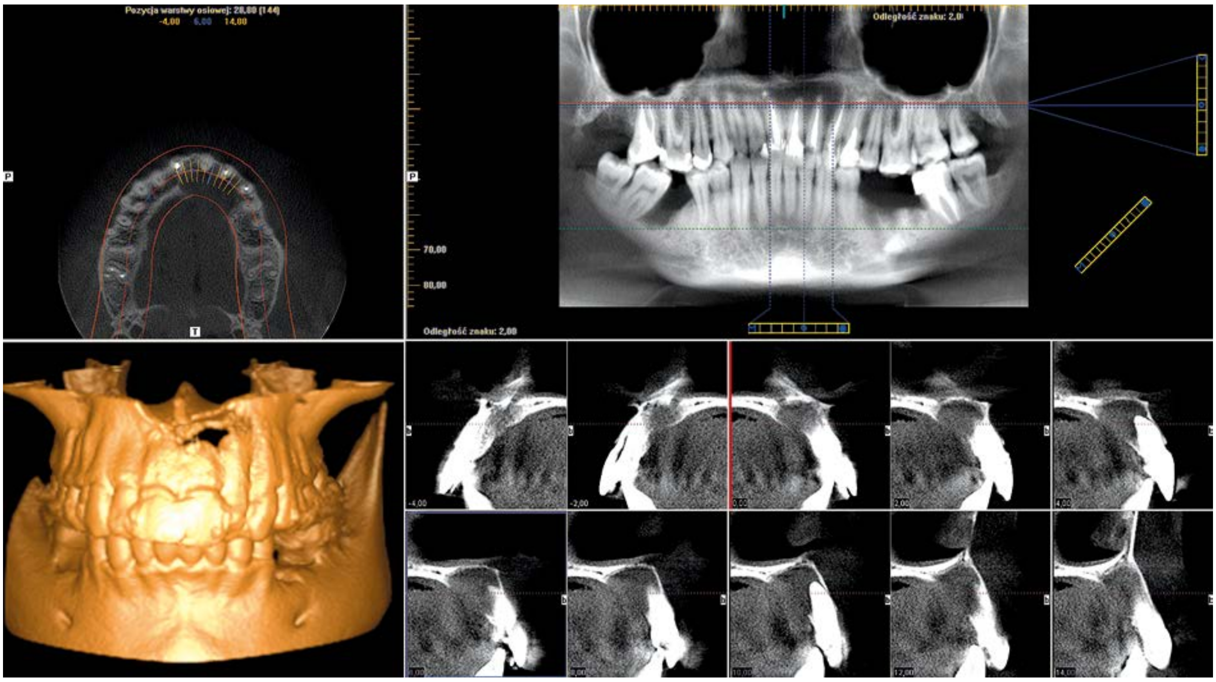

Photo 9. Cone beam coputed tomography planning. The cyst extending from the upper right central incisor to the upper left canine through the width of the maxilla from the buccal to the palatal site

augmentation procedures. It provides an esthetic visualization of the implants. The program offers a library with more than 8000 different implants and abutments, a 3D transparency tool for investigation of the position of the nerve towards the implants, and precise assessment of bone density.

Conclusions

Modern, interactive visualization software allows one to precisely plan the treatment, to control its course and to specify its effects. Programs such as InVivo Anatomage and SimPlant (Materialise) are useful tools in comprehensive treatment of the maxillofacial area.

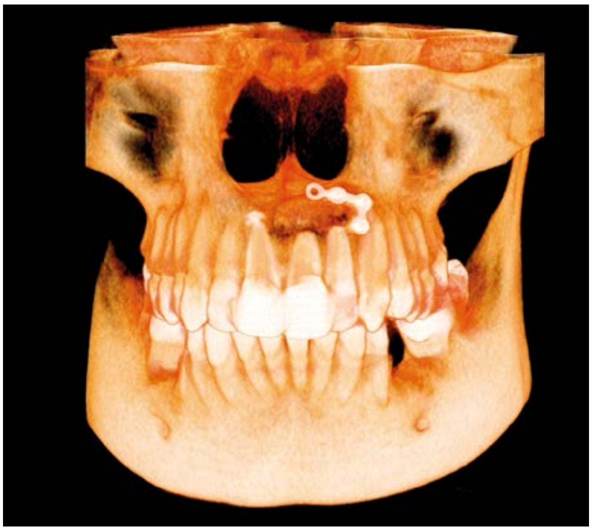

Photo 10. Post-cystectomy visualization of maxillary bone defect augmented with autogenic pre-osteoblasts on allogenic scaffold using InVivo anatomage software

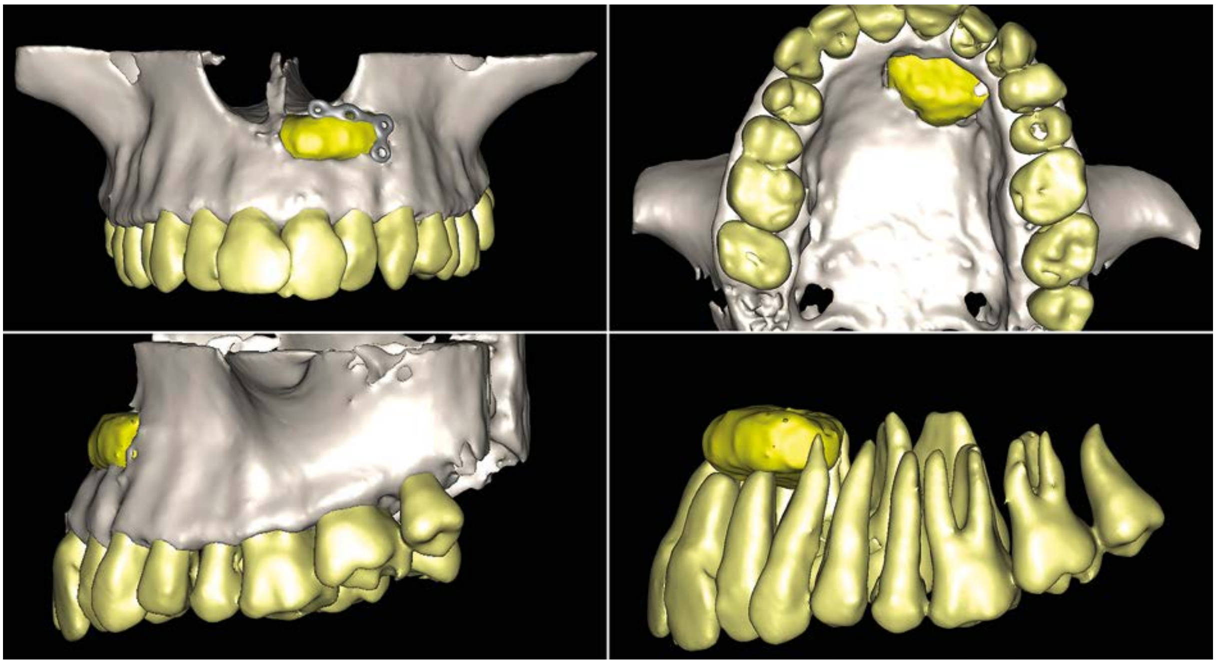

Photo 11. Post-surgery visualization of augmentation of post-cystectomy bone defect in the maxilla using Simplant software

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