X-ray Based Planning of Implant-Prosthetic Treatment for Oncological Patients after Post-Resective Maxilla/Mandible Reconstruction - Quantitative Evaluation of Implantation Results

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Abstract. The aim of this work was to develop a tool for X-ray based planning of implant-prosthetic treatment for oncological patients after post-resective maxilla or mandible reconstruction. To extend the possibilities of the currently developed system, in cooperation with oncologists and dentists we designed a module of qualitative analysis of pre and postoperative CT image datasets. The surgeon can fuse pre and postoperative images basing on matching markers identified in both datasets. After a proper transformation, matched datasets can be analysed in order to evaluate applied treatment. Using the software the surgeon can measure such parameters as: the accuracy of implants axes locations and orientations, the diameters, lengths and depth of applied implants in comparison to the designed in preoperative planning. It is rational to apply X-ray images to analyse the efficiency of implantprosthetic treatment, since the oncological patients need to be examined regularly to supervise the risk of neoplasm recurrence. The paper presents also our concept to apply Cone Beam Computed Tomography (CBCT), as a significantly less invasive imaging technique in comparison to the standard CT. The 3D dataset reconstructed will be applied similarly to the currently applied in the software CT.

Keywords: bioimplant, implantoprosthetic treatment, image guided surgery, CBCT

1. Introduction

Implant-prosthetic treatment tool for oncological patients was developed as a module of the computer Maxillo-Facial Surgery System (MFS System), which supports oncologic surgery in the maxillo-facial area [1]. MFS System is a part of a wider project which aims at developing methods of maxillofacial area neoplasm medical treatment using bioimplant-innovative, custom made product of tissue engineering together with relevant computer aided surgical procedures. Developed solution is the first complex system for virtual planning of neoplasm resection, designing initial geometry of personalized bio-implant to reconstruct a resulted bone loss, aiding surgical procedure, postoperative evaluation of the results, as well as planning and supporting of succeeding dental implant-prosthetic treatment. Application of medical images and navigation systems enables accurate neoplasmidentyfication, proper resection and bone loss reconstruction and suitable dental restoration. Treatment procedures implemented in MFS system are designed in cooperation with surgeons and dentists to ensure effectiveness of oncologic surgery with lower invasiveness and lower risk of complications but also facial aesthetics and restoration of masticatory apparatus function. Implantoprosthetic treatment module implemented in Maxillo-Facial Surgery System provides virtual planning and intra-operative support, which were described in detail in the previous paper [2]. First purpose of the present work was to extend existing implantoprosthetic treatment module of qualitative and quantitative analysis tool for implantation evaluation. Second purpose of this work is a preliminary assessment of Cone Beam Computed Tomography (CBCT) application validity in MFS system.

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2. Quantitative Evaluation of Implantation Results

A module for a quantitative evaluation of the implantation results has been developed. Evaluation is performed via the comparison of a pre-operative scenario with an actual implant position. Implantoprosthetic module implemented in MFS system allows for virtual planning of an implantoprosthetic treatment. The application of different visualization including: DICOM projections, 3D surface model and a pseudo panoramic view for selected plane (Fig 1), enables accurate implant placement. Virtual planning procedure was performed using CT image of a skull phantom.
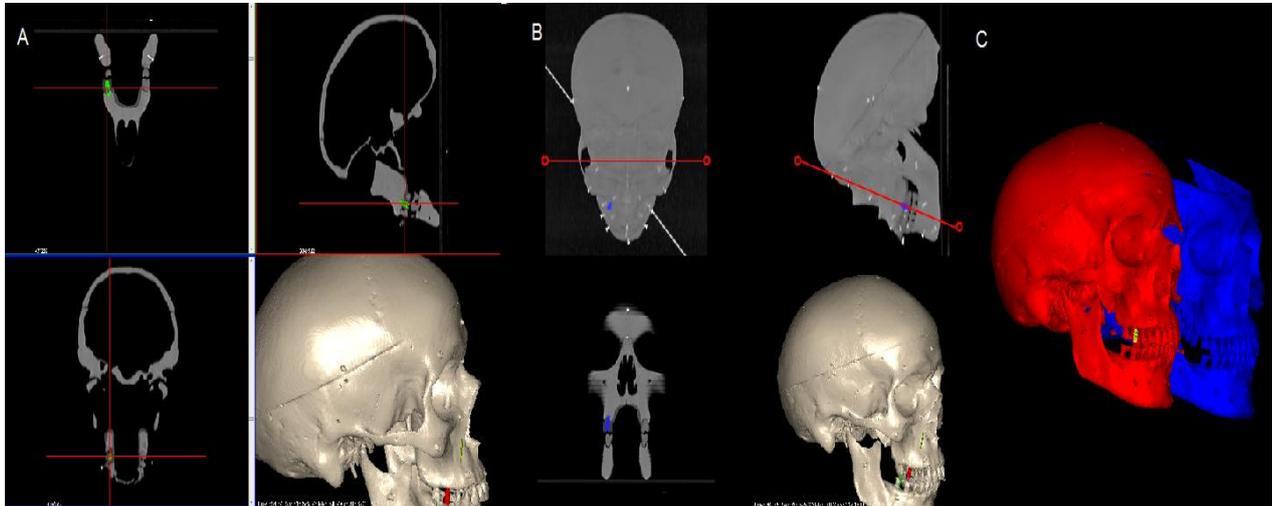

Fig. 1: Dental implant localization planning (A,B) and matching procedure (C)

Image based pre-operative planning concerns precise localization of selected dental implant model. In the intra-operative phase, the software supports surgeon to insert dental implant according to pre-operative plan with navigated drilling tool. Dental implant is accurately placed through controlling drilling location, direction and depth. Such solution is an option to surgical guide. Intra-operative phase was omitted in this study on skull phantom. Treatment result was simulated in CBCT image. Pre-operative CT image and post-operative CBCT results were fused using matching procedure (Fig.1 C). Matching of the two datasets (virtual planning scenario and postoperative data) can be performed using two different scenarios 3D DICOM projection adjustment and anatomical landmarks fitting (Fig. 3). The phantom CT dataset used for virtual planning was matched with this CBCT datasets with simulated implantation.

There are two basic types of measurements implemented in MFS system: a distance measurement and an angle measurement. Both can be done in particular projection and between different projections, independently for two datasets. Furthermore, it is possible to measure distance and angles between structures indicated in two separate datasets. Compatibility of projections from both datasets is ensured through the matching procedure. Matching procedure accuracy can be measured as linear distance between the same anatomical landmarks indicated on two different data sets (by TRE error measure). Accuracy of implantation can be assessed by measurement of parameters such as an implantation depth an implantation angle (Fig. 2), distance from the adjacent teeth or distance between virtually planned and actual implants. Such measurements provide a quantitative evaluation of the implantation procedure.
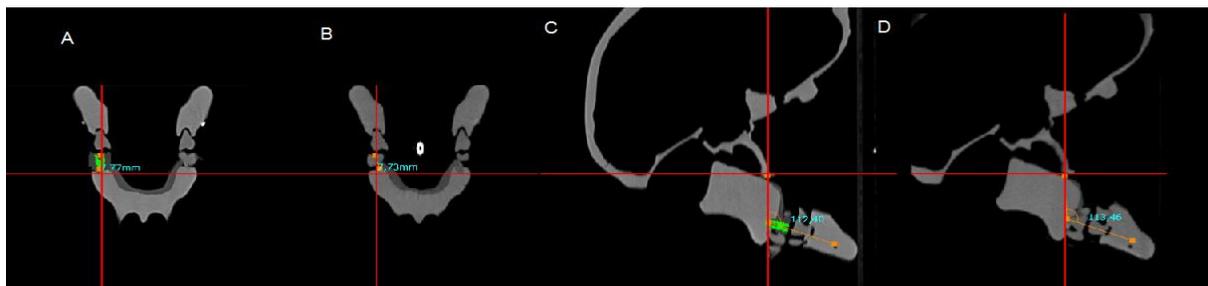

Fig. 2: Implant depth and angle measurements: virtual planning (A, C) and simulated post-operative dataset (B, D).

2.1. X-ray imaging in maxillo-facial surgery system

In MFS system CT images are used for several different purposes: identification of tumour; resection planning; designing initial geometry of personalized bio-implant to reconstruct a resulted bone loss on the basis of patient anatomy; planning of fixation procedure for bone reconstruction and implantoprosthetic treatment; intra-operative guided bone resection, implant fixation or dental implantation; postoperative evaluation of the resective and reconstructive surgery results and implant-prosthetic treatment. Depending on the particular case and medical indications, treatment with the support of MFS system would require at least one 3D X-ray images acquisition to even three or more.

So far, convectional helical fan-beam CT datasets were primarily used in Maxillo-Facial Surgery System as well established imaging technique in computer aided surgery. The main motivation for CBCT datasets introduction to MFS system were lower radiation dose, cost reduction and thus greater access to such treatment. CBCT technique as oral and craniofacial imaging corresponds to the needs of the maxillo-facial surgery and at the same time could be an alternative for conventional CT.

Developed Maxillo-Facial Surgery System provides CBCT dataset visualization the same as CT datasets. Moreover, CBCT is a promising option for CT in MFS system, datasets can be processed and reconstructed similarly to CT. Hereby, CBCT could replace CT in some cases , be complementary imaging technique or be used as a follow-up imaging. The choice of imaging technique will depend on the particular medical case: the tumor location, the reconstruction area or bioimplant material. The advantages of the use of CBCT, as well as its limitation should be taken into account specifying the area of CBCT application in Maxillo-Facial Surgery System (MFS System).

2.2. Cone beam computed tomography

In recent years, the cone beam computer tomography (CBCT) was developed and successfully introduced in oral and maxillofacial radiology and dental practise [3]. In CBCT scanners, low-energy anode and 3D X-ray beam are used to capture approximately 150-600 radiographic view during single rotation. X-ray source and detector synchronously move around patients head, scan time is ca. 40 seconds [4]. 3D Filtered back projection algorithms are used to generate 3D volumetric data from basis projection images [5]. Results are 3D isotropic voxels and submilimeter resolution. An effective dose of radiation is significantly reduced (even 98 %) compared to conventional CT. All these advantages together with affordable costs made CBCT scanners the tool in oral and maxillofacial imaging thereby in dental practise. On the other hand , CBCT have some limitations. First of all, grey levels in CBCT images are not Hounsfield units (HU) as in medical CT [6]. The same anatomical areas are represented with different grey levels using CBCT and conventional CT scanners [7]. CBCT does not allow for accurate bone density assessment [8]. Gray scale obtained for different type of bone vary from the range of -1500 to over 3000 [9], while for soft tissue gray scale provides little information. What is more the region of the same density can reveal different greyscale in the CBCT reconstruction dataset [10]. Furthermore, noise and artefacts are common in CBCT images. Lower signal-to-noise radio in CBCT revealed as inconsistent grey levels in the projections image. Scattered radiation affects CBCT machines more than conventional CT, which causes streaks artefacts in the reconstruction, further reduction of soft-tissue contrast and altered the density values of all other tissues. Darks streaks are also an effect of beam hardening in the presence of highly absorbing material such as metal (even enamel or light metal as titanium). Too great interval between projections (under-sampling) causes aliasing patterns (Moire patterns), strips radiating from the edge of the volumetric data . Ring artefacts, in turn are visible as concentric rings centred around rotation axis, most prominent in homogenous media [11]. All these limitations affects segmentation thresholds, as well as final effect of segmentation procedure and resulted 3D surface model or even projection view quality [12], [13].

2.3. Material

Two different datasets were used in this study, involving CBCT images of two patients and different scanners. Dataset A was acquired with NewTom VG scanner (acquisition parameters: 110 kV, 3mA, DFOV 15cm, slice thickness 0.3mm, pixel resolution 0.3/0.3 mm). Dataset B was acquired with Carestream Health CS 9300 (acquisition parameters: 90 kV, 4mA, DFOV 10cm, slice thickness 0.18mm, pixel resolution 0.18/0.18 mm).

2.4. CBCT datasets visualization in MFS system

Imaging dataset are processed into several various representation in MFS system: three projections (axial, sagittal, frontal), panoramic view, projections with segmented anatomical structures, volume projection of different anatomical structures using ray-casting method, 3D surface models generated from segmented bone (in STL format).

Distortion of HU in CBCT makes segmentation with CT threshold values ineffective (Fig. 3). For bone CT values were assumed from 266 to 3071, for skin from -718 to -177. CT threshold values overestimate related areas. Relevant anatomical structures are segmented together with adjacent structures. Narrowed threshold range was manually selected and applied to both CBCT datasets: from 750 to 2750 for compact bone and from -680 to -380 for skin tissue. Segmentation effect was improved (Fig. 3). However instead whole bone tissue, only compact bone was segmented.
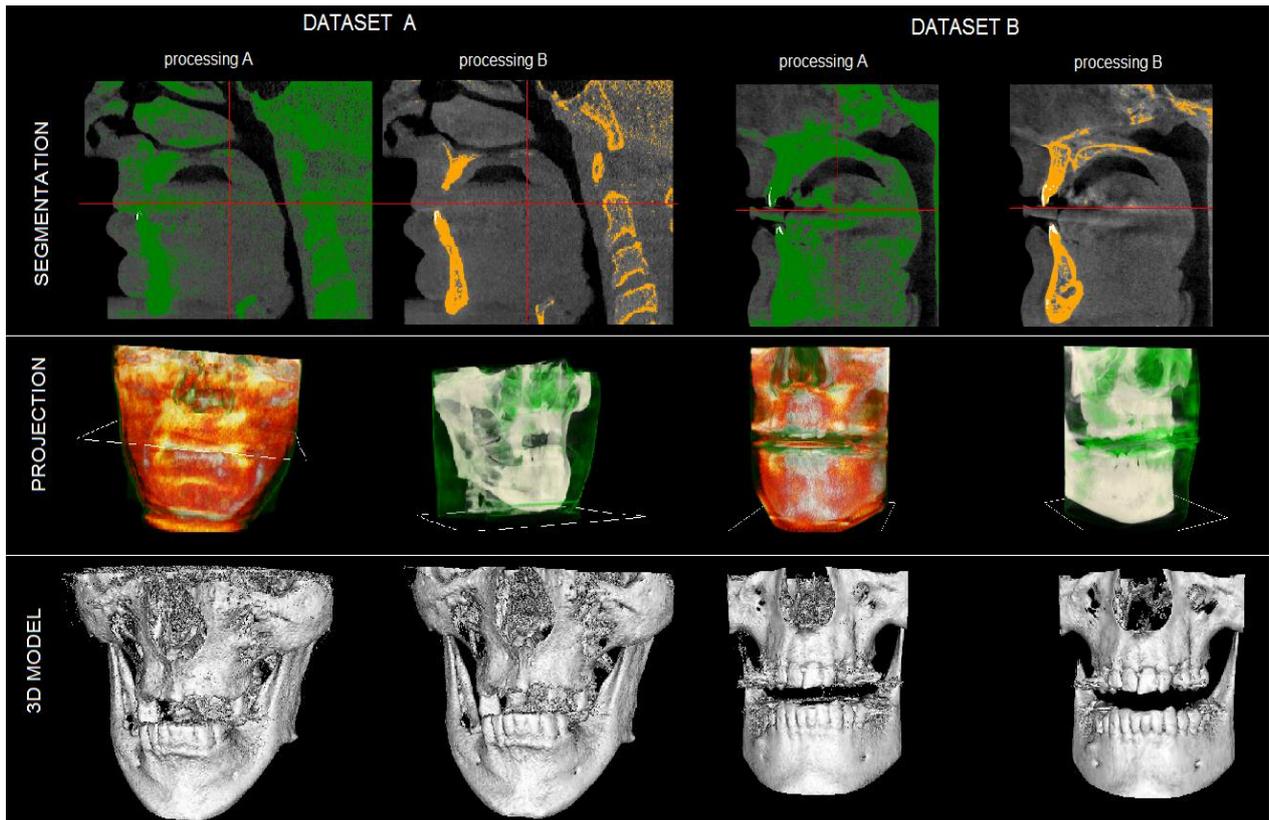

Fig. 3: CBCT patient datasets visualization for standard CT processing (processing A) and CBCT adjusted processing (processing B).

Imaging data visualization in the form of volume projection (textural visualization) is common for CBCT software analysis. Similarly as in the case of segmentation, different thresholds are required. Furthermore, various soft tissues are not clearly visible in volume projection of CBCT. Relatively clear bone and skin visualization can be obtained using appropriately selected thresholds and opacity levels .

Surface 3D models were generated after adjusted segmentation and preliminary filtration with 3D median filter (3x3x3) (Fig. 3) and compared to models generated for CT compact bone thresholds. Median filter was used for partially elimination of noise effects (spread dots in segmented images).

Various types of artifacts can be observed in analyzed CBCT images: noise, streaks, beam hardening, aliasing artifacts and ring patterns. Those artifacts together with HU distortion significantly affect quality of volume projections and 3D models.

3. Conclusions

This paper presents procedure of quantitative evaluation of dental implantation, which was developed in the Maxillofacial Surgery System. The new tool enables final assessment of patient's implant-prosthetic treatment. An accuracy of final implant placement is also valuable feedback information for a surgeon.

Moreover,the system has been enhanced with the CBCT feature. CBCT technique as oral and craniofacial imaging corresponds to the needs of the maxillo-facial surgery. CBCT datasets can be visualized and processed in MFS provided additional adjustment. Despite the processing improvements, CBCT dataset visualisation quality is still inferior to the CT datasets, which results directly from typical CBCT artifacts. Resulting CBCT visualization quality seems to be sufficient for the general treatment evaluation, as well as for implantoprosthetic treatment. However, CBCT application in tumour resection should be evaluated in the future.

4. Acknowledgements

5. References

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