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Computer assisted assessment of progressing osteoradionecrosis of the jaw for clinical diagnosis and treatment

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Abstract: Osteoradionecrosis (ORN) is a serious side effect of oncologic radiation therapy. Often, surgical removal of the affected skeletal tissue is indicated. In craniomaxillofacial surgery, partial or total resection of the upper or lower jaw implies a severe impairment of the patient's quality of life. Up to now, clear display of ORN is still a challenge. This part of the project is dedicated to medical visualization of progressing ORN for clinical diagnosis. Currently, clinical diagnosis of ORN is mostly based on computer tomography (CT). With regard to its high advantages as e.g. reduced radiation dose, we additionally evaluate cone beam computer tomography (CBCT). After registration on a suitable reference and refined image processing and segmentation, all patient's CT-/CBCT-data are subjected to various rendering techniques configured for the respective purpose, namely visualization of destructive and/or sclerotic skeletal alterations, consideration of cortical or trabecular bone, and analysis based on CT or CBCT. Recent achievements within the project were demonstrated with special focus on evaluation of both, CT and CBCT as well as on close cooperation with the clinical setting.

Keywords: 3D-visualization; CBCT; CT; mandible; osteoradionecrosis.

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1 Introduction

Necrotic changes in the skeletal tissue due to radiation therapy within oncologic treatment are a serious burden. Once started, osteoradionecrosis (ORN) of the jaw bone is continuously progressing through the affected organ [1]. Therefore, partial or total resection of the jaw often remains the only means for stopping further progression of the disease. Until now, clear classification of the disease's progression is still a challenge in clinical diagnosis.

Thereby motivated, a detailed research project about computer assisted evaluation of necrotic changes in craniofacial skeletal tissue was initiated. Currently, helical computer tomography (CT) is still the primary three-dimensional imaging modality in this context. However, as characterized by high resolution, good bone contrast, and especially less radiation compared to helical CT, upcoming cone beam computer tomography (CBCT) provides high benefit for the patients, who are often subjected to frequent radiological image acquisition. Therefore, evaluation of CT-based versus CBCT-based application of the developed methods is an integral part of the research.

As the project is aimed to support clinical diagnosis and therapy planning, close interaction with the clinical setting is special focus of this work.

2 Methods

Long-term cancer patients often present numerous radiological data sets. In a first step, available CT- and CBCT-data are registered on a suitable reference data set. A standard algorithm referring to normalized mutual information metrics mostly provides satisfactory results. Thereafter, the data are upsampled to identical dimensions with isotropic voxel size of 0.5 mm side length or below for an immediate comparison.

For ORN, destructive as well as sclerosing processes are observed in the skeletal tissue. The first phenomenon corresponds to decreased Hounsfield values whereas sclerosis is indicated by increasing ones. Both, cortical and trabecular bone are concerned.

For further processing, three image stacks from each data set are stored. In the first one, the original anatomy is saved. For the second one, we mask out the entire mandible, especially its cortical hull, including some axial rim of 2 mm soft tissue. Thirdly, we do the same for the spongious bone including some rim through the cortical bone, but omitting soft tissue as far as possible. If necessary, additional image processing steps as sharpening or denoising are applied.

Thereafter, these image stacks are – either single or combined – subjected to slice oriented direct volume rendering with specially designed transfer functions depending on i) the concerned tissue, namely cortical or trabecular bone, ii) the pathological changes under consideration, e.g. sclerotic or destructive alterations, and finally iii) whether CT or CBCT data are evaluated. As detailed knowledge is available for Hounsfield values from helical CT, qualitative and quantitative analysis is possible there. For full display of the inhomogeneous distribution of the Hounsfield values, we mostly apply a physical color scale (dark blue – light blue – green – yellow – orange –red). In the contrary, by its high spatial resolution and refined bone contrast, CBCT is well suited for rendering bone inner structure but with less – or, at least, up to now less understood – quantitative significance. Therefore, we refer to a two-tone visualization here (see Figure 1). Up to now, four visualization approaches with different focus and requirements have been developed within the project, see inter alia [2, 3]. For image processing, programming, and visualization, the toolbox Amira®, versions 4.x–6.x, FEI Company, Berlin, Germany, is used as platform [4, 5]. All approaches are developed in the sense of a prototype where the 3D-model can be rotated, zoomed, and clipped according to arbitrary planes.

Validation is performed inter alia by refined comparison with the CT-/CBCT-images and projections of the original slices to selected planes through the lesions (see Figure 2B) as well as results of histological diagnosis. Nevertheless, special emphasis is put on interpretation of

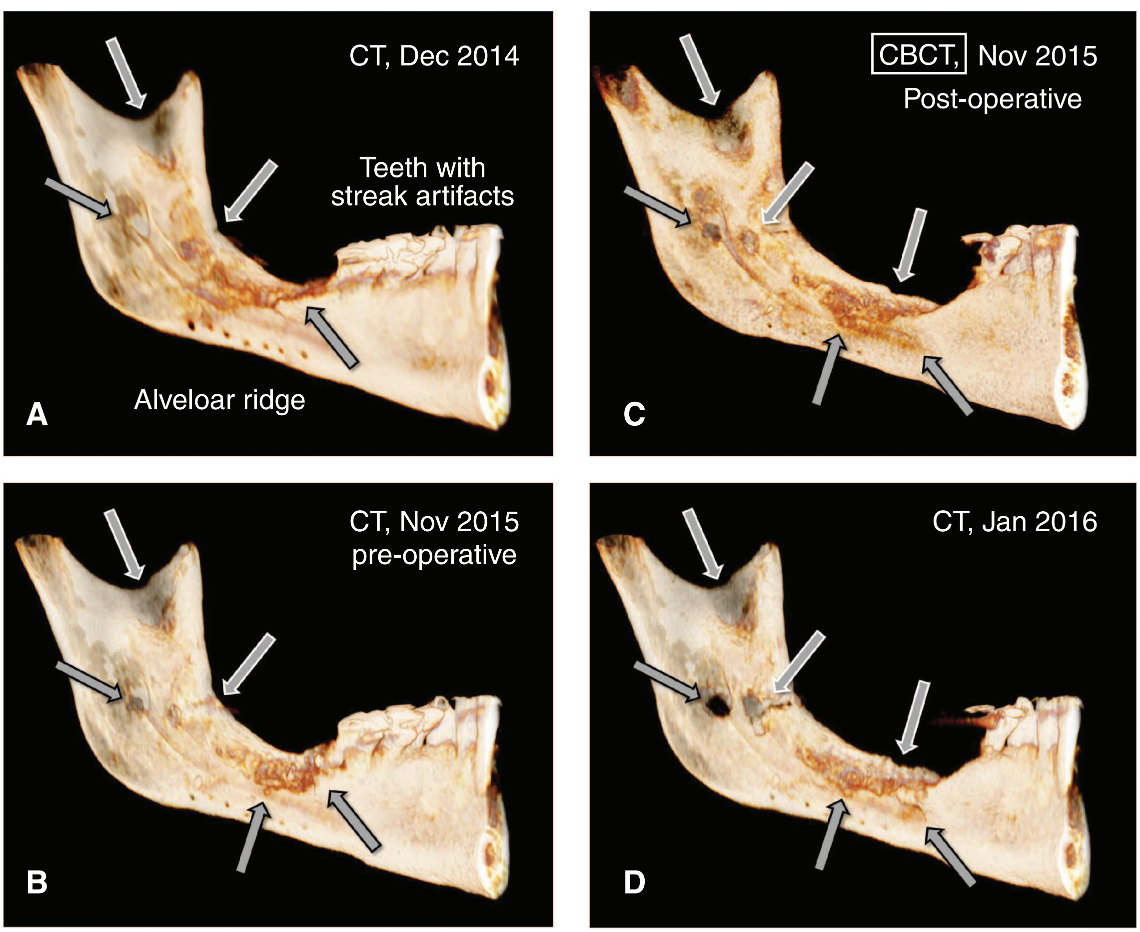

Figure 1: Two-tone visualization of progressing ORN, based on CT (A, B, D), based on CBCT (C).

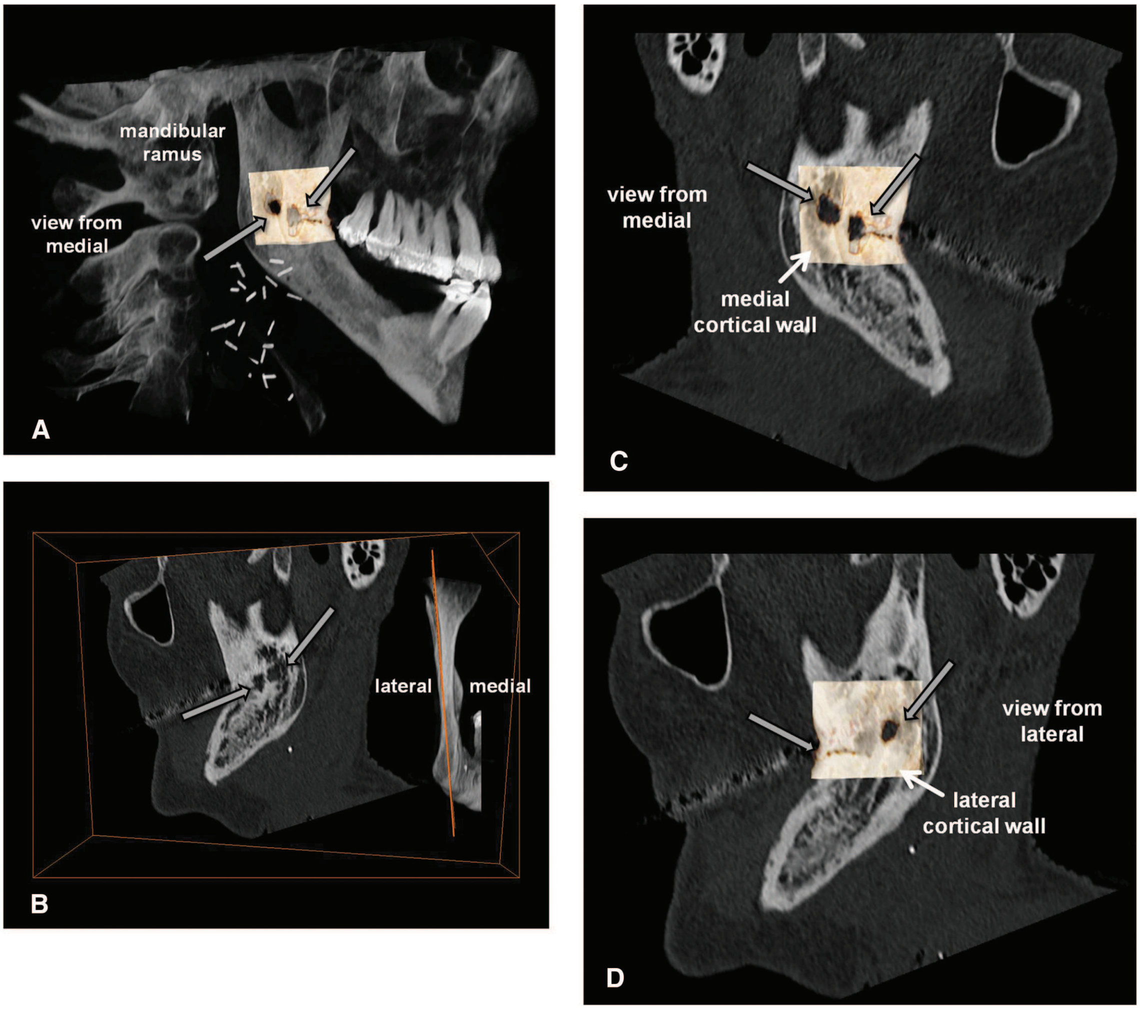

Figure 2: A) Visualization of the patient's anatomy with highlighted detail of the mandibular ramus, B) projection of the CT-data to the indicated plane through the ramus, C, D) detail of the cortical wall with projection of the CT-data (black and white, in opaque rendering), view from medial (C), and view from lateral (D).

the computer assisted results with regard to the clinical situation resp. patient's feedback, f. i. localization of pain (see Figure 2).

Ethical approval: The research related to human use has been complied with all the relevant national regulations, institutional policies and in accordance the tenets of the Helsinki Declaration, and has been approved by the local ethical institution.

3 Results

The current stage of the project is exemplarily demonstrated for a case of progressing mandibular ORN after radiation therapy due to oral cancer in combination with other risk factors as heavy smoking and regular alcohol consumption (male, 61 years). First signs of ORN mainly in the left alveolar ridge were diagnosed in December 2014 (see Figure 1A). In November 2015, the affected tissue was surgically removed (see Figure 1B). Notably, the post-operative imaging was performed by CBCT (see Figure 1C). From autumn 2015, the patient complained about severe pain in the left mandibular ramus. In January 2016, diagnostic follow-up CT was acquainted (see Figure 1D).

All available follow-up CT-/CBCT-data were evaluated by transparent 3D-visualization using a logarithmic two-tone transfer function. For CBCT (see Figure 1C), scale and transparency had to be changed compared to helical CT (see Figure 1A, B and D). Severe destructive processes were observed in the alveolar ridge starting from near the mandibular angle, continuously progressing towards the chin. Notably, for both, CT and CBCT, the detailed skeletal structure can be equally studied without any difference in quality. For the visualization based on CBCT (see Figure 1C), the observed alterations of the alveolar geometry were vice versa corroborated by the CT-based visualizations before and afterwards (see Figure 1B and D). However, for CBCT, we – at least currently – refrain from any quantitative analysis which is possible for follow-ups based on helical CT [2]. Management of streak artifacts, though visible inter alia at the teeth (see Figure 1A–D), is satisfactory.

With regard to the clearly localized pain in the left mandibular ramus reported by the patient, a detail analysis based on the CT-data from January 2016 was performed (see Figure 2). Thereby, several mainly destructive skeletal lesions were found at the respective place confirming that the reported pain was caused by skeletal reasons. For validation and further evaluation, a plane through the respective part of the mandibular ramus was introduced and the original CT images were projected on (see Figure 2B). The considered detail of mandibular cortical bone was visualized from medial and from lateral view with the projected CT-image in opaque rendering (see Figure 2C and D). As pathological alterations are visible from both sides, laterally and medially, it had to be concluded that the lateral as well as the medial cortical hull of the mandibular ramus are affected. This finding was confirmed by axial CT images.

Based on the found correspondences between the clinical situation and the computational analysis, feedback of the physicians is very positive for diagnosis support as well as for surgical planning and evaluation. With regard to the high number of radiological images often acquainted for oncologic patients, diagnosis efficiency, which e.g. means that the visualization can be studied by some glances, is additional focus of the research which was evaluated very positively.

4 Conclusion and outlook

Exemplarily, destructive alterations due to progressing ORN in the mandibular bone were evaluated by 3D-visualization techniques. The analysis could be performed based on CT as well as on CBCT. By clinical feedback, the skeletal lesions shown by the visualization were identified with locations of severe patient's pain.

The close cooperation with the clinicians will be further endorsed with regard to diagnosis support and efficiency, surgery planning, and therapy evaluation. The combined analysis of CT and CBCT will be intensively followed. As, often, ORN patients are subjected to frequent radiological imaging, they will definitely profit from the reduced radiation dose of CBCT compared to CT. For quantitative evaluation of CT, promising results could be reported in [2] where further research will be spent on. The final aim is scanner-independent qualitative and quantitative classification of ORN based on CT and CBCT. Especially, the latter one is still a challenge.

To close with, in clinical diagnosis, necrotic changes, septic and/or aseptic, tumor relapse, infections, and other pathologies are to be differentiated. For many cases, nuclear imaging as PET, PET/CT, SPECT, SPECT/CT is applied. Therefore, future activity is planned for combined evaluation with these modalities. By first superposed test visualizations, promising results were shown.

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