European Journal of Radiology 80 (2011) e389–e393

Contents lists available at ScienceDirect

European Journal of Radiology

journal homepage: www.elsevier.com/locate/ejrad

Tilting the jaw to improve the image quality or to reduce the dose in cone-beam computed tomography

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ARTICLE INFO

Article history:
Received 4 July 2010
Accepted 4 October 2010

Keywords:
Cone-beam computed tomography (CBCT)
Micro CT
Metal artifact reduction
Image quality

ABSTRACT

Objective: The image quality in cone-beam computed tomography (CBCT) should be improved tilting the mandible that contains two dental titanium implants, within the relevant range of motion.
Materials and methods: Using the mandible of a five-month-old pig, CBCT was performed varying the accelerating voltage, beam current, the starting rotation angle of the mandible in the source-detector plane and the tilt angles of the jaw with respect to the source-detector plane. The different datasets were automatically registered with respect to micro CT data to extract the common volume and the deviance to the pre-defined standard that characterizes the image quality.
Results: The variations of the accelerating voltage, beam current and the rotation within the source-detection plane provided the expected quantitative behavior indicating the appropriate choice of the imaging quality factor. The tilting of the porcine mandible by about 14° improves the image quality by almost a factor of two.
Conclusions: The tilting of the mandible with two dental implants can be used to significantly reduce the artifacts of the strongly X-ray absorbing materials in the CBCT images. The comparison of 14° jaw tilting with respect to the currently recommended arrangement in plane with the teeth demonstrates that the applied exposure time and the related dose can be reduced by a factor of four without decreasing the image quality.

1. Introduction

Dentomaxillofacial X-ray cone-beam computed tomography (CBCT) has been applied to visualize the hard tissues for planning the implant placement and for the selection of the implant [1–4]. Based on these data, the oral surgeon can precisely identify the location of the mandibular nerve and other important structures [1] and decide subsequently, which part of the bony tissue will be removed for the implant placement and which part of the bone is needed to guarantee the mechanical stability of the patient's mandible. Unfortunately, CBCT cannot be utilized likewise for the post-operative imaging as validation and follow-up, because massive artifacts that appear as dark bands and streaks cover the region around the metal implant [5] that are also well-known from other metallic implants [6,7]. As consequence, the post-operative imaging only relies on radiographs. Because of the high X-ray absorption of the implant material, the number of transmitted photons available to visualize the surrounding tissue is extremely low, so that the artifact formation becomes easily understandable. The X-ray absorption also explains the orientation of the artifacts from the implant towards the stronger absorbing teeth and bony components. This behavior is especially evident between distinct, strongly absorbing implants.

The present communication deals with the possibilities of the CBCT operator to reduce the artifacts caused by standard dental titanium implants. First, the operator can increase the accelerating voltage until the maximum value has been reached. The increase is supportive, since the implants get more and more transparent for the photons of higher and higher energy. Admittedly, the soft and hard tissues of interest also become more and more transparent. Therefore, the improvement of the overall image quality is expected to be only limited or even absent. Second, the operator can prolong the exposure time or increase the beam current, which leads to a linear increase of the number of available photons but which also linearly raises the dose for the patient. The benefit for the signal-to-noise ratio only improves by the square root of the exposure time. Hence, the prolongation of the exposure time will not really improve the entire imaging procedure. Third, we have realized that using CBCT the head of the patient is oriented that teeth, potential

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doi:10.1016/j.ejrad.2010.10.001

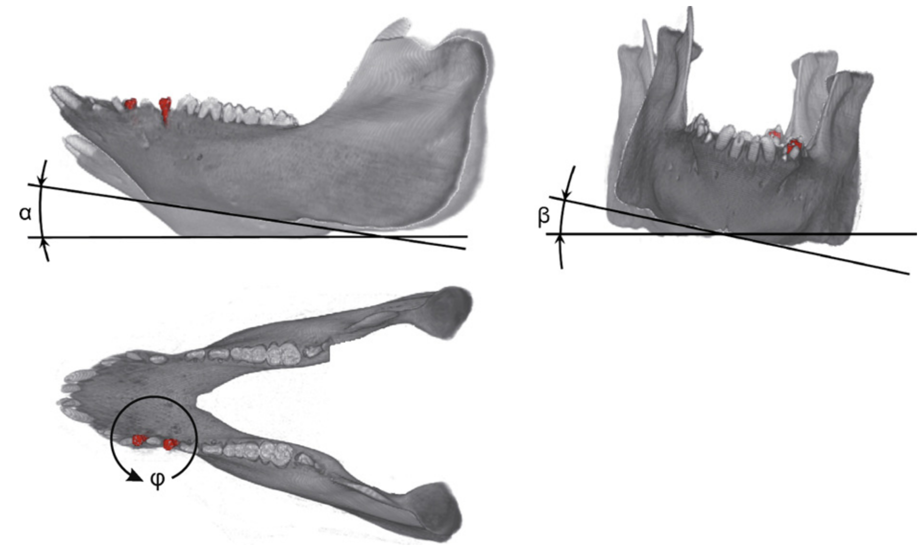

Fig. 1. The red color indicates the position of the two titanium implants in the 3D representations of the porcine mandible. The angles α and β denote the tilt of the mandible with respect to the source-detector plane of the CBCT in frontal and sagittal planes, respectively.

implants as well as X-ray source and detection unit are arranged in a single plane. This choice, however, is the worst case, since the highly X-ray absorbing components in line cause the strongest possible artifacts. Therefore, we hypothesize that the tilting of the head significantly reduces these artifacts. The present study should clarify how far the tilting of the head within the reasonable range improves CBCT image quality. The effect should become especially clear for patients with multiple implants, because the tilting can prevent the overlapping of the highly X-ray absorbing materials in the projections to be recorded. Therefore, the improvement of the CBCT image quality by tilting the jaw containing two dental titanium implants should be quantified within a relevant range of motion. Micro computed tomography with conventional or synchrotron radiation sources performed on the cylindrical part of the porcine mandible containing the dental implants provides the almost artifact-free standard of comparison.

2. Materials and methods

2.1. Specimen preparation

To avoid any radiation damage of test persons, the lower jaw of a five-month-old, meliorated country pig has been selected for the post-mortem experiment. This choice should be an appropriate model to prove the hypothesis. The anatomy of the pig's jaw cannot be simply translated to humans, although mini-pigs are regarded as adequate model [8]. The tongue and pieces of the vertebral body were added [9] to built a more realistic situation. For the better handling, the entire specimen was laminated in plastics. Because the pig was in the late phase of deciduous dentition two gaps for implantation were found mesial and distal of the canine. Two Ti-implants (SLA-surface, Straumann AG, Villeret, Switzerland) each 4.1 mm in diameter and 10 mm long were inserted according to the recommendations of the manufacturer.

2.2. CBCT imaging

The 3D Accuitomo 60 (Accuitomo, Morita, Japan) served for the CBCT image acquisition. For all CBCT scans the exposure time corresponded to 17 s. The accelerating voltage was varied between 70 and 80 kVp and the X-ray beam currents between 1 and 10 mA to check their influence on the image quality. In order to determine the influence of the specimen position with respect to the source and detection unit, the specimen was manually rotated to $\varphi = 0^\circ$, $\varphi = 30^\circ$, $\varphi = 45^\circ$, and $\varphi = 90^\circ$ around the implant's axis and was tilted in the frontal and sagittal planes by the angles α and β as represented in Fig. 1.

The projection data were exported and reconstructed by means of the modified Feldkamp algorithm using the Skyscan Nrecon^{TM} software (Skyscan, Kontich, Belgium). The reconstructed data volume corresponds to a cylinder 6 cm in diameter and 6 cm high, which contains the two Ti-implants inserted.

2.3. Micro computed tomography

For the micro computed tomography (μCT) measurements, a cylinder of the porcine mandible, which included the two implants, was extracted by means of a 3 cm hollow drill.

First, this cylinder was scanned using a conventional system, i.e. SkyScan 1172^{TM} (SkyScan, Kontich, Belgium) using an accelerating voltage of 100 kVp (with Al/Cu filter), a beam current of 100 μA, an exposure time of 2.7 s per projection, and a pixel size of 17.4 μm in rotation steps of 0.4° between 0° and 360°. The reconstruction was carried out with the Skyscan software package.

Second, synchrotron radiation-based μCT (SRμCT) measurements were performed at the beamline W 2 (HASYLAB at DESY, Hamburg, Germany) by the standard setup in absorption contrast mode, operated by the GKSS Research Center [10]. Here, the X-ray beam is monochromatic. The photon energy was chosen to 76 keV and the pixel size to 6.7 μm. This parameter choice resulted in a spatial resolution of 14.6 μm, experimentally derived from the projection of a sharp edge of a highly X-ray absorbing material. It corresponds to the 10% value of the modulation transfer function [11].

Since the cylindrical specimen was almost 3 times larger than the field of view (1536 × 730 pixels and 10.4 mm × 4.9 mm, respectively) 1440 projections were acquired at asymmetric rotation axes and combined with pixel precision before reconstruction at two height levels [12]. Because of the limited number of projections acquired and to increase the contrast (density resolution) the data were binned with a factor of 2 before reconstruction [13]. For easier data handling, the data were also binned by a factor of two after reconstruction. Hence, the volume, reconstructed by means of the filtered back-projection algorithm, consists of 32.3 mm × 32.3 mm × 8.9 mm of isotropic 27 μm-wide voxels.