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Research article

Artifact reduction from dental implants using virtual monoenergetic reconstructions from novel spectral detector CT

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ABSTRACT

Objectives: Image quality in head and neck imaging is often severely hampered by artifacts arising from dental implants. This study evaluates metal artifact (MA) reduction using virtual monoenergetic images (VMI) compared to conventional CT images (CI) from spectral-detector computed tomography (SDCT).

Methods: 38 consecutive patients with dental implants were included in this retrospective study. All examinations were performed using a SDCT (IQon, Philips, Best, The Netherlands). Images were reconstructed as conventional images (CI) and as VMI in a range of 40–200 keV (10 keV increment). Quantitative image analysis was performed ROI-based by measurement of attenuation (HU) and standard deviation in most pronounced hypo- and hyperdense artifact, fat and soft tissue with presence of artifacts. Qualitatively, extent of artifact reduction, assessment of soft palate and cheeks were rated on 5-point Likert-scales by two radiologists. Statistical data evaluation included ANOVA and Wilcoxon-test with correction for multiple comparisons; interrater-agreement was determined by intraclass-correlation coefficient (ICC).

Results: The hypo- and hyperattenuating artifacts showed an increase and decrease of HU-values in VMI_{high} (CI/$VMI_{200\,keV}$: −218.7/−174.4 HU, $p = 0.1$; and 309.8/119.2, $p \leq 0.05$, respectively). Artifacts in the fat, as depicted by image noise did also decrease in VMI_{high} (CI/$VMI_{200\,keV}$: 23.9/16.4, $p \leq 0.05$). Qualitatively, hyperdense artifacts were decreased significantly in VMI ≥ 100 keV (e.g. CI/$VMI_{200\,keV}$: 2(1–3)/3(1–5), $p \leq 0.05$). Artifact reduction resulted in improved assessment of the soft palate and cheeks (e.g. CI/$VMI_{200\,keV}$: 2(1–4)/3(1–5) and 2(1–5)/3(1–5), $p \leq 0.05$). Overall interrater agreement was good (ICC = 0.77).

Conclusions: Virtual monoenergetic images from SDCT reduce metal artifacts from dental implants and improve diagnostic assessment of surrounding soft tissue.

1. Introduction

Imaging the head and neck by computed tomography is the standard method for evaluation of tumors, inflammation and injuries. Further, it is needed for diagnosis and treatment of head and neck cancer. In daily practice image quality is often severely hampered by artifacts arising from dental implants consisting of different metal alloys and concerning a high number of patients [1,2]. Most abundant phenomena resulting in artifacts from dental implants are (i) beam-hardening caused by stronger absorption of low energy photons compared to higher energy photons leading to hyperdense artifacts, (ii) photon starvation due to complete absorption of photons resulting in hypodense streaks, and (iii) scatter artifacts which are caused by great differences of attenuation of the metal implants and the adjacent soft tissue resulting in increased image noise. These artifacts combine to strong interferences that decrease image quality of the implant itself as well as its surrounding tissue (teeth, bone and soft tissue) [3–8]. There are several parameters that determine the severity of metal artifacts (MA) such as composition of the metal implant, image acquisition, and image reconstruction parameters [4]. Different concepts have been proposed to reduce MA in conventional single energy CT imaging: High tube voltage (kV_p), high tube current (mAs), modified collimation, and

Abbreviations: MA, metal artifacts; VMI, virtual monoenergetic images; DECT, dual energy computed tomography; SDCT, spectral detector computed tomography; CI, conventional images; CIN, corrected image noise; ICC, intraclass correlation coefficient

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suitable filters for reconstruction; however, altering radiation dose to reduce MA needs to be monitored carefully, especially in imaging of young patients or in patients undergoing repeated examinations [4]. Several post-processing algorithms are available for MA reduction (so called MAR algorithms) that have been shown to reduce artifacts caused by dental implants [9,10]. Besides, virtual monoenergetic images (VMI) from dual-energy computed tomography (DECT) can be used for MA reduction [11–13]. DECT assesses attenuation of photons of low and high energies separately and therefore allows for reconstruction of VMI i.e. images that would result from acquisition with a true monoenergetic X-ray. VMI of higher keV are less susceptible for beam hardening and have shown to reduce MA from a variety of implants [11–18]. Recently a detector based approach to DECT became available, referred to as spectral detector CT (SDCT) [19,20]. To the author's knowledge, it has not been investigated if artifacts caused by dental implants can be reduced using VMI from SDCT. Therefore, the aim of this study is to evaluate the extent of artifact reduction in such images as compared to conventional image reconstructions in spectral detector computed tomography.

2. Material and methods

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Informed consent was waived due to retrospective study characteristics. All imaging was performed for clinical indications. No scan was conducted explicitly for the purpose of this study.

2.1. Patient enrollment

60 consecutive patients with artificial dental implants or fillings were screened for inclusion in this retrospective mono-centric study. All patients were referred to our department for oncologic staging examination with suspicion of or known malignancy. Further inclusion criteria comprised: a) age ≥ 18 years; b) contrast enhanced SDCT examination with standardized protocol as described below. 22 patients were excluded due to presence of artifacts that were not attributed to artificial dental implants or fillings.

2.2. Imaging protocol

All scans were performed on a clinically available SDCT scanner (IQon, Philips, Best, The Netherlands). Patients were placed in a head-first supine position. A body weight-adapted volume of iodinated contrast agent (Accupaque 350 mg/ml, GE Healthcare, Little Chalfort, UK) was administered intravenously at a flow rate of 3.5 ml/s followed by a 30 ml saline flush. The scan was started with 40 s delay after reaching the threshold value of 150 HU in the descending aorta. Tube current modulation was activated in all patients (DoseRight 3D-DOM; Philips, Best, The Netherlands), resulting in an average tube current time product of 281.1 ± 105.1 mAs and a DLP of 375.4 ± 106.0 mGy*cm. Additional scan parameters were: collimation 64 × 0.625 mm; rotation time 0.33 s; pitch 1.296; tube voltage 120 kVp; $CTDI_{vol}$ 11.7 mGy.

2.3. Image reconstruction

Images were reconstructed with a slice thickness and section increment of 1 mm in the axial plane. For reconstruction of conventional images (CI), information from both detector layers is combined, thus image reconstruction is carried out using standard-of-care hybrid-iterative reconstruction algorithms ($iDose^4$, Denoising preset 3, Philips, Best, The Netherlands). For reconstruction of virtual monoenergetic images, a dedicated spectral reconstruction algorithm is applied (Spectral B, Denoising preset 3, Philips, Best, The Netherlands). VMI were reconstructed with 40–200 keV (10 keV increment). Thus, in total 17 image reconstructions were compared, all analyses were performed on the proprietary image viewer (IntelliSpace Spectral DiagnosticSuite, Philips, Best, The Netherlands).

2.4. Quantitative image analysis

Quantitative image assessment was performed based on regions of interest by two radiologists with 2 and 3 years of experience in oncologic imaging. Readers were explicitly free to decide on the slice with the most pronounced hypo- and hyperdense artifacts to avoid any bias in image preselection. ROI were drawn in the following regions: Hypo- and hyperdense artifacts, soft tissue with presence of artifacts (i.e. soft palate, mouth floor), soft tissue without presence of artifacts (sternoclavicular muscle) and subcutaneous fat (ROI placement is illustrated in Electronic Supplement 1). Standard ROI size was 100 mm^2, size was possibly reduced to avoid unrepresentative tissue or areas. Attenuation (HU) and standard deviation were recorded. According to earlier studies, image noise was considered to be indicative of artifact burden [17,18,21]. To correct for general lower image noise in high keV reconstructions, we calculated the corrected image noise (CIN) as difference between image noise in soft tissue with and without visual presence of artifacts, as proposed recently [18].

2.5. Qualitative image analysis

Two radiologists who were not involved in quantitative analysis assessed image quality subjectively on 5-point Likert scales. As differences in MonoE occur gradually, distinct keV-levels of 70 keV, 100 keV, 130 keV, 160 keV and 200 keV were chosen for subjective assessment in addition to CI. Levels were chosen in order to identify relevant changes in image assessment and not to obscure differences by repetitive rating of (too) similar images. The following criteria were evaluated:

i) extent of hypodense and of hyperdense metal artifact [(5) Metal artifacts are absent; (4) minor; (3) moderate, (2) pronounced; (1) massive];
ii) assessment of soft palate/mouth floor [(5) full diagnostic quality; (4) diagnostic interpretability is not affected by minor streaks; (3) minor artifacts only marginally affect the interpretability; (2) restricted diagnostic interpretability; (1) insufficient diagnostic interpretability by metal artifacts];
iii) assessment of adjacent buccal soft tissue [(5) full diagnostic quality; (4) diagnostic interpretability is not affected by minor streaks; (3) minor artifacts only marginally affect the interpretability; (2) restricted diagnostic interpretability; (1) insufficient diagnostic interpretability by metal artifacts];
iv) image noise [(5) excessive; (4) severe; (3) moderate; (2) little; (1) no perceptible noise].

Subsequently, conventional reconstructions were identified and readers were asked to determine presence of new/unexpected artifacts as compared to CI on a tertiary scale [(1) no new/unexpected artifacts; (2) new/unexpected artifacts without impairment of diagnostic assessment; (3) new/unexpected artifacts with impairment of diagnostic assessment].

In addition, one reader determined the origin of the artifacts as either attributed to fillings/crowns or implants.

2.6. Data analysis

Interval scaled data are reported as mean and standard deviation, ordinal scaled data as median, 10- and 90-percentile. Descriptive statistics are reported as fraction and percentage. Data analysis was performed using JMP Software (v13, SAS Institute, Cary, USA). After testing for normal distribution using Shapiro-Wilk test, further analysis