Radiotherapy and Oncology xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Radiotherapy and Oncology

journal homepage: www.thegreenjournal.com

Original article

Metal artefact reduction for accurate tumour delineation in radiotherapy

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ARTICLE INFO

Article history:
Received 1 June 2017
Received in revised form 16 September 2017
Accepted 20 September 2017
Available online xxxx

Keywords:
Dual energy CT
Iterative metal artefact reduction
Delineation uncertainty
IGRT

ABSTRACT

Background and purpose: Two techniques for metal artefact reduction for computed tomography were studied in order to identify their impact on tumour delineation in radiotherapy.
Materials and methods: Using specially designed phantoms containing metal implants (dental, spine and hip) as well as patient images, we investigated the impact of two methods for metal artefact reduction on (A) the size and severity of metal artefacts and the accuracy of Hounsfield Unit (HU) representation, (B) the visual impact of metal artefacts on image quality and (C) delineation accuracy. A metal artefact reduction algorithm (MAR) and two types of dual energy virtual monochromatic (DECT VM) reconstructions were used separately and in combination to identify the optimal technique for each implant site.
Results: The artefact area and severity was reduced (by 48–76% and 58–79%, MAR and DECT VM respectively) and accurate Hounsfield-value representation was increased by 22–82%. For each energy, the observers preferred MAR over non-MAR reconstructions ($p < 0.01$ for dental and hip cases, $p < 0.05$ for the spine case). In addition, DECT VM was preferred for spine implants ($p < 0.01$). In all cases, techniques that improved target delineation significantly ($p < 0.05$) were identified.
Conclusions: DECT VM and MAR techniques improve delineation accuracy and the optimal of reconstruction technique depends on the type of metal implant.

Modern advances in image-guided radiotherapy (IGRT) have increased the accuracy of dose delivery and decreased the need for large planning target volumes (PTV) [1]. The high level of accuracy in delivery has, however, increased requirements for accuracy in target delineation. Even deviations on a scale of a few millimetres may result in increased irradiation of organs at risk (OARs) or geographic target miss, and hence have significant negative impact on patient outcomes. Today, it is recognized that target and OAR delineation variability is a major source of uncertainty in radiotherapy (RT), and considerable work has been done in order to reduce factors that lead to this variability [2–6].

A major cause of delineation variability is streaking and beam hardening artefacts from metallic implants. Metallic artefacts are a significant clinical issue in RT, causing decreased delineation confidence, decreased dose calculation accuracy, and increased time spent on manually delineating pixels affected by the artefacts [7–11].

The two main methods described in the literature for reduction of metal artefacts are dual energy computed tomography (DECT) virtual monochromatic (VM) extrapolations [12] and iterative metal artefact reduction (MAR) algorithms [13–15]. DECT VM images between 95 and 150 kilo electron volt (keV) levels have been found to reduce beam hardening artefacts from various metallic prostheses effectively [16–18], while VM images around 40–70 keV show some clinical value by improving contrast to noise ratios (CNR) between soft tissues [19,20]. MAR algorithms also show clinical value by reducing metal artefacts [21,22] and improving dose calculation accuracy [23]. Using DECT and MAR in combination may enable a further reduction of artefacts [24].

In this work, we focused on the impact of metal artefact reduction on target delineation, hypothesizing that DECT and MAR techniques can reduce RT-specific uncertainties. We evaluated different combinations of DECT VM and MAR techniques both quantitatively and qualitatively in order to identify the optimal solutions for radiotherapy imaging in different anatomical regions. Furthermore, we investigated the potential of DECT VM and MAR to improve the accuracy of target delineation in patient and phantom images.

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https://doi.org/10.1016/j.radonc.2017.09.029
0167-8140/

Please cite this article in press as: Kovacs DG et al. Metal artefact reduction for accurate tumour delineation in radiotherapy. Radiother Oncol (2017), https://doi.org/10.1016/j.radonc.2017.09.029

Materials and methods

We compared six different reconstruction methods using dental, spine, and hip implant phantoms and corresponding patient cases. The six evaluated reconstructions were (1) 120 peak kilo voltage (kVp) (standard-of-care) (2) 120 kVp MAR (3) 70 keV DECT (4) 70 keV DECT MAR (5) 130 keV DECT and 6) 130 keV DECT MAR. Image acquisition details are described in the supplementary material. 70 and 130 keV levels were selected because they represent the mean energy of the polychromatic spectrum in a 120 kVp image while maximizing the CNR and the optimal balance between beam hardening artefact reduction and soft tissue contrast, respectively [17,25].

These reconstructions were evaluated according to (A) the size/severity and HU-values of the artefacts, (B) the resulting image quality as evaluated by five observers and (C) the delineation variability from five observers.

Phantoms

Three phantoms (Fig. 1) with metal implants were constructed to represent common causes of metal artefacts as seen in clinical practice: (1) a set of human teeth fixated in paraffin wax with a removable amalgam-filled tooth (in-house construction) (2) surgical spine screws (Globus Revere Pedicle Screw System and K2M titanium rod) (3) a hip implant (Zimmer Segmental System Proximal Femoral Provisional and Femoral Head Provisional).

Low contrast targets were arbitrarily shaped of polycaprolactone (Polymorph, Thermoworx Ltd.) and placed in a water-tank together with the respective implants. The metal implants could be removed without affecting the positioning of the other objects in the tank. CT scans of each phantom were acquired with and without the presence of the metal implants.

Patients

This study was approved by the institutional review board and the regional ethics committee (H-15006887). Patients who were referred for radiotherapy, had metal implants and were older than 50 years were offered inclusion. Informed consent was obtained for experimentation with human subjects. The DECT scans were performed immediately after the treatment planning CT scan (64-slice single-source CT scanner, Siemens Somatom Definition AS, Siemens Health Care, Forchheim Germany). Images were then reconstructed using the MAR algorithm (iMAR on VA48A SW, Siemens AG, München Germany). VM images were reconstructed using the Dual Energy application (syngo.CT Monoenergetic 2016, Siemens AG). Detailed settings and scanning procedure are described in the supplementary material (section "Image Acquisition" and Table A1).

Study A: Artefact quantification

Phantom scans with and without metal present were acquired within one imaging session. The low-contrast targets and the surrounding water were segmented in the images without metal. These contours were then transferred to images with metal.

A program was written (MATLAB 2015b, MathWorks® Natick Massachusetts, U.S.A) to evaluate the area and severity of the artefacts, as well as the accuracy of HU-value representation of the water and low-contrast target within a region surrounding the metal implant.

The artefact area, HU-value median and interquartile range was calculated, where the latter was interpreted as an expression of artefact severity.

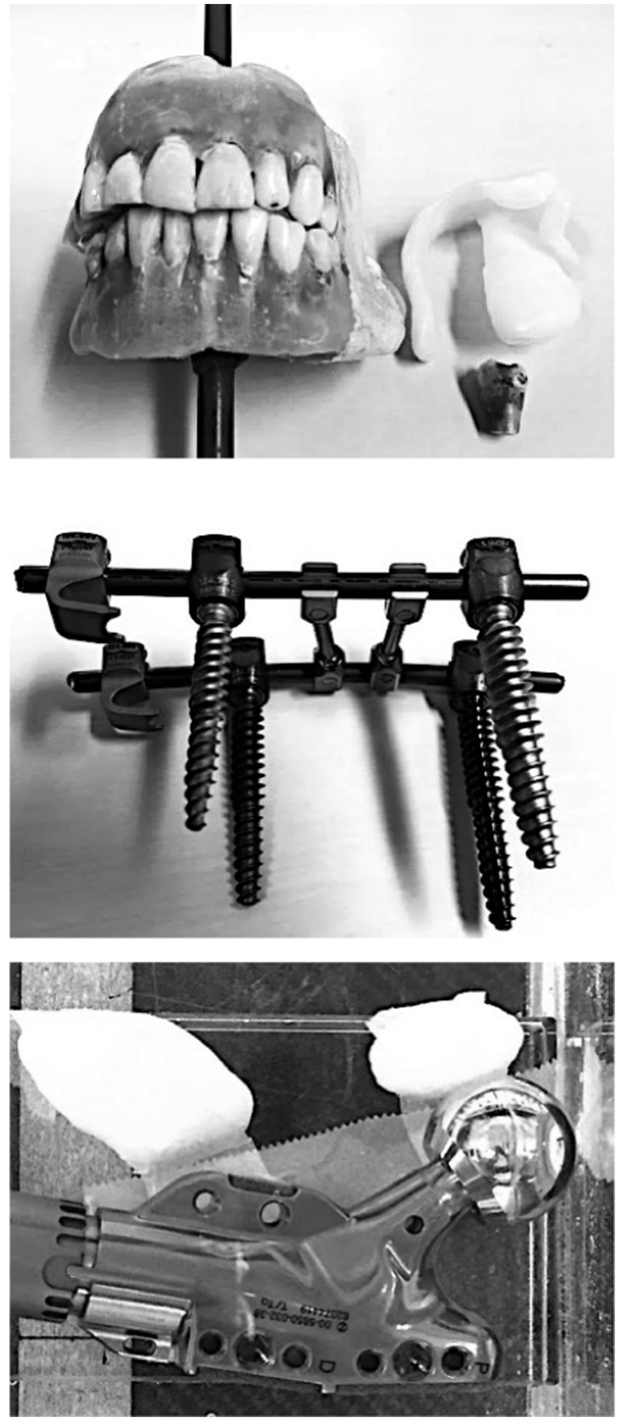

Fig. 1. Phantoms used for quantitative analysis. Left: Dental phantom with low-contrast target removed for visibility (during the scan the low-contrast target was placed inside the oral cavity) and removable tooth with amalgam filling. Middle: Surgical Spine Screws. Right: Hip implant placed in water tank with two low-contrast targets.

The 95% confidence intervals (CI) of the pixel intensity values of water and of the low-contrast target regions were estimated from the non-metal reference. If pixel intensity values in the image with metal were within the expected 95% CI for each corresponding region, the pixels were considered "accurately represented". Pixels outside this range were considered "artefact".

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