Oral Oncology 50 (2014) 221–227

Contents lists available at ScienceDirect

Oral Oncology

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

Can dual-energy CT improve the assessment of tumor margins in oral cancer?

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A R T I C L E   I N F O

Article history:
Received 3 August 2013
Received in revised form 28 November 2013
Accepted 2 December 2013
Available online 25 December 2013

Keywords:
Dual energy
Multidetector computed tomography
Image quality
Oral cancer
Tumor margin

S U M M A R Y

Objectives: The aim was to investigate the image quality of dual-energy computed-tomography (DECT) compared to single-energy images at 80 kV and 140 kV in oral tumors.
Materials and methods: Forty patients underwent a contrast-enhanced DECT scan on a definition flash-CT. Four reconstructions (80 kV, 140 kV, mixed (M), and optimum-contrast (OC)) were assessed by four blinded readers for subjective image quality (10-point scale/10 = best). For objective quality assessment, linear attenuation measurements (line density profiles (LDP)) were positioned at the tumor margin, and the difference between minimum and maximum was calculated. Signal-to-noise ratios (SNR) were measured in the tongue.
Results: The mean image quality for all readers was 5.1 ± 0.3, 8.4 ± 0.3, 8.1 ± 0.2, and 8.3 ± 0.2 for the 140 kV, 80 kV, M, and OC, respectively ($P < 001$ between 140 kV and all others). The mean difference between the minimum and maximum within the LDP was 139.4 ± 59.0, 65.7 ± 29.5, 105.1 ± 46.5, and 118.7 ± 59.4 for the 80 kV, 140 kV, M, and OC, respectively ($P < 001$). The SNR for the tongue was 3.8 ± 2.1, 3.8 ± 2.1, 4.2 ± 2.4, and 4.1 ± 2.3 for the 80 kV, 140 kV, M, and OC, respectively.
Discussion: DECT of oral tumors offers high image quality, with subjectively rated image quality and attenuation contrast at the tumor margin similar to that of 80 kV; DECT, however, provides a significantly higher SNR compared to 80 kV.

Introduction

In the diagnosis of oral cancer, multi-detector computed tomography (MDCT) is a first-line diagnostic device because of its broad availability, the ability to perform whole-body tumor staging, and an overall good sensitivity and specificity for the detection of oral cancer [1]. For both the radiologist and the surgeon, the information provided by the image enables accurate tumor staging and treatment planning for the resection of the tumor. The primary site, the size of the primary tumor, and the proximity to the bone, are all factors that influence the choice of initial treatment [2]. However, due to the complex anatomy in the oral cavity and the metal artifacts of dental restoration, imaging of oral cancer is challenging [3].

The recently introduced technology of dual-energy computed tomography (DECT) has been reported to provide an improved image quality compared to standard single-energy CT at 120 kV. Initial work using the first- and the second-generation of DECT scanners analyzed image quality in the abdomen and even in the head and neck region, and found an overall improved image quality based on a subjective analysis [4–6].

Abbreviations: MDCT, multi-detector computed tomography; kV, kilovolt; DECT, dual-energy computed tomography; mAs, milliampere seconds; SNR, signal-to-noise ratio; M, mixed; OC, optimum contrast; LDP, line density profile; HU, hounsfield units.

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http://dx.doi.org/10.1016/j.oraloncology.2013.12.001

To date, these studies have focused on the subjective analysis of image quality, and usually do not have the low-dose CT images for comparison. Furthermore, these studies focus on the image quality in healthy subjects and do not provide data about the image quality of the tumor region.

The aim of this study was to analyze the image quality, as well as the ability to identify the tumor margins subjectively and objectively in patients with oral cancer, using a second-generation dual-energy CT, and compare these results to images acquired with 80 kV and 140 kV. As a secondary aim, we wanted to compare the two common dual-energy reconstruction techniques, called 'mixed' and the 'optimum contrast'. Finally, we wanted to evaluate the image noise in images with streaking artifacts caused by dental fillings.

Materials and methods

The research protocol for this prospective study was approved by the Institutional Review Board of our institution (Medical University of Vienna, Vienna, Austria; protocol 1014/2009) and was conducted in accordance with the ethical standards of the World Medical Association (Declaration of Helsinki). All patients gave written, informed consent to participate in the study. All patient data were completely anonymized at the start of the study and were not de-blinded for the duration of the study.

We included consecutive patients who were clinically and histologically diagnosed with a primary oral tumor, and who were referred for MDCT at our department for tumor staging. Exclusion criteria were a known adverse reaction to iodinated contrast agents, renal insufficiency (serum creatinine > 1.5 mg/dl), a history of prior chemo- or radiation therapy, age younger than 18 years, and pregnancy. Details of the included patients are given in the Results section.

Dual-energy scan

All scans were performed in the supine position with the arms positioned parallel to the chest, using a second-generation, dual-energy multidetector CT scanner (Siemens Somatom Definition Flash CT, Siemens Medical Solutions, Forchheim, Germany). To reduce streaking artifacts from dental fillings, all scans were performed in the open-mouth position. To ensure that the mouth remained open, a specific device made from a plastic polymer was introduced into the mouth (Burnett BiDirectional TMJ Device, Medrad, Indianola, PA, USA).

For each patient, 100 ml of intravenous contrast media (Iomeron 400 mg/ml; Bracco, Italy) were injected using a 21-gauge cannula via a cubital vein, at a flow of 3 ml/s followed by a 40 ml saline chaser. All scans were performed with a scan delay of 60 s after the beginning of contrast injection.

The scan ranged from the base of the skull down to the supraclavicular region. All scans were performed with dual-energy CT, with $2 \times 32 \times 0.6$ mm collimation, a pitch of 1, and 80 kV/270 mAs for tube A, and SN140 kV/135 mAs for tube B in a craniocaudal scan direction. The maximum field of view (FOV) for the high-energy image measured 33-cm in diameter; the reconstructed FOV was individually chosen to match the size of the head and neck region.

Dual-energy image reconstruction

Images for both the 80 kV and the 140 KV scan were reconstructed as transverse sections at a slice thickness of 1.0 mm and an increment of 0.8 mm using a common soft tissue kernel (D26) and a window width/window level of 40/350 HU. For the reconstruction of the mixed image (M), the ratio between 80 kV and 140 kV was 6:4, as recommended by the manufacturer and published previously [7]. This resulted in three transverse image series for each patient: 80 kV; 140 kV; and M (Mixed).

In addition, images were then transferred to an offline workstation (Syngo Multi Modality Workplace [MMWP], Siemens AG, Healthcare Sector, Forchheim, Germany, Version VE 36A) for reconstruction of the 'optimum contrast' images, using clinically available, dedicated software to reconstruct transverse optimum contrast images with the same slice thickness and reconstruction interval as that used for the other reconstructions.

Image quality analysis

To assess image quality, one position within the 140 kV stack from each patient, where the tumor was clearly visible, was selected by one reader (M.T.). At this position, one axial image of each reconstructed stack (80 kV; 140 kV; M; OC) was exported. All information that would enable a reader to identify the reconstruction technique was removed from the images. Images were then numbered randomly and displayed consecutively as one image stack containing 160 single images. Four readers (H.R., 16 years of experience; C.C., 28 years of experience; F.W., 11 years of experience; J.F., 7 years of experience) evaluated images for overall image quality and the ability to delineate the tumor margins. They used a 10-point scale, with 10 being the highest and 1 being the lowest score. The score was further used to determine the image quality as non-diagnostic (1–2), low (3–4), moderate (5–6), good (7–8), and excellent (9–10).

Line density analysis

These selected images were further used for the line density analysis. Images were exported to an offline computer and the free, available software, JmageJ (ImageJ 1.45 s; National Institutes of Health, USA; http://imagej.nih.gov/iJ) was used for further evaluation. The tumor was identified on the 140 kV image, and one reader (M.T., 11 years of experience) positioned a line of 10 mm in length and a thickness of one pixel perpendicular to the tumor margins with one-half the line within the tumor and one-half within the healthy tissue. This measurement was applied for each of the four different images per patient at the exact same position, angle, and length. Mean hounsfield units (HU) were measured at 23 points within this 10 mm line by the software, which was called the line density profile (LDP). All measurements were exported to an Excel database, and the minimum and maximum HU value within these 10 mm was identified. For further statistical work-up, the steepness of the curve was calculated as the difference between the maximum and the minimum HU value within the 10 mm.

Signal-to-noise analysis

To assess the signal-to-noise ratio (SNR), the same data sets and software as previously described were used. A round ROI with a fixed size (5 mm diameter) was positioned by one reader (M.T., 11 years of experience) within skeletal muscle in the autochthone back musculature, the tongue, and the tumor. These ROIs were positioned at the exact same position and size for all four image reconstructions.

For the analysis of streaking artifacts, axial images containing metal dental fillings were selected for the analysis. For this analysis, only patients with dental restorations were included ($n = 23$). An oval ROI was positioned close to a metal artifact within homogeneous soft tissue (e.g., tongue) for all four reconstructions at the same size and position.

The mean HU and the standard deviation of the attenuation of the ROI were noted. The signal-to-noise ratio was calculated as the quotient between the signal (mean HU) and the noise