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Research paper

Dual-energy computed tomography in patients with cutaneous malignant melanoma: Comparison of noise-optimized and traditional virtual monoenergetic imaging

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ABSTRACT

Objective: The aim of this study was to investigate the impact of noise-optimized virtual monoenergetic imaging (VMI+) reconstructions on quantitative and qualitative image parameters in patients with cutaneous malignant melanoma at thoracoabdominal dual-energy computed tomography (DECT).

Materials and methods: Seventy-six patients (48 men; 66.6 ± 13.8 years) with metastatic cutaneous malignant melanoma underwent DECT of the thorax and abdomen. Images were post-processed with standard linear blending (M_0.6), traditional virtual monoenergetic (VMI), and VMI+ technique. VMI and VMI+ images were reconstructed in 10-keV intervals from 40 to 100 keV. Attenuation measurements were performed in cutaneous melanoma lesions, as well as in regional lymph node, subcutaneous and in-transit metastases to calculate objective signal-to-noise (SNR) and contrast-to-noise (CNR) ratios. Five-point scales were used to evaluate overall image quality and lesion delineation by three radiologists with different levels of experience.

Results: Objective indices SNR and CNR were highest at 40-keV VMI+ series (5.6 ± 2.6 and 12.4 ± 3.4), significantly superior to all other reconstructions (all $P < 0.001$). Qualitative image parameters showed highest values for 50-keV and 60-keV VMI+ reconstructions (median 5, respectively; $P \leq 0.019$) regarding overall image quality. Moreover, qualitative assessment of lesion delineation peaked in 40-keV VMI+ (median 5) and 50-keV VMI+ (median 4; $P = 0.055$), significantly superior to all other reconstructions (all $P < 0.001$).

Conclusion: Low-keV noise-optimized VMI+ reconstructions substantially increase quantitative and qualitative image parameters, as well as subjective lesion delineation compared to standard image reconstruction and traditional VMI in patients with cutaneous malignant melanoma at thoracoabdominal DECT.

1. Introduction

The incidence of cutaneous malignant melanoma has been steadily increasing worldwide [1–3]. Computed tomography (CT) is currently the most widely used technique in staging and follow-up of patients with metastatic cutaneous melanoma [4]. Malignant melanoma metastasizes via blood and lymphatic vessels, and the most common metastatic sites include skin, soft tissues, liver, lung, and brain [4]. Because of their small tumor volume and sometimes poor contrast enhancement, cutaneous and subcutaneous melanoma lesions may be missed at thoracoabdominal staging CT.

Dual-energy computed tomography (DECT) allows for image reconstruction using post-processing algorithms facilitating an optimized evaluation of patients with metastatic melanoma [5,6]. Moreover, the calculation of virtual monoenergetic images (VMI) has shown an improved iodine signal at low-keV levels and a better tumor delineation due to increased contrast in previous studies [7,8]. In this context, a noise-optimized virtual monoenergetic reconstruction algorithm (VMI+) has been developed to reduce image noise at low-keV levels by performing a regional spatial frequency-based recombination of low and high energy datasets to obtain the best possible image contrast [9]. This reconstruction technique has shown favorable results in prior

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studies evaluating vascular and oncologic imaging [9–13]. However, noise-optimized VMI+ has not been applied to assess image quality in staging and follow-up of patients with cutaneous malignant melanoma so far.

The purpose of this study was to assess image quality and lesion delineation of virtual monoenergetic reconstructions in patients with metastatic cutaneous malignant melanoma in thoracoabdominal DECT examinations.

2. Material and methods

This retrospective study was approved by the local institutional review board, and the requirement for written informed consent was waived.

2.1. Patient population

The picture archiving and communication system (PACS) databases of our department were screened to identify patients with histologically proven cutaneous malignant melanoma and corresponding findings in thoracoabdominal DECT examinations between September 2014 and February 2016. General exclusion criteria for DECT imaging were known allergies to iodinated contrast material, pregnancy, age younger than 18 years, and impaired renal function (glomerular filtration rate < 45 mL/min). Moreover, DECT examinations with severe motion artifacts, contrast material extravasation, and examinations with deviations from the standard contrast media injection protocol or standard DECT protocol were excluded.

The final study group consisted of 76 patients (mean age 66.6 ± 13.8 years; range 30–89 years) with DECT examinations (25 initial staging examinations and 52 follow-up examinations), including 48 men (mean age 67.8 ± 13.1 years; range 38–89 years) and 28 women (mean age 64.7 ± 14.9 years; range 30–86 years).

2.2. DECT image acquisition

All single-phase DECT examinations of the thorax and abdomen were performed on a third-generation dual-source scanner (SOMATOM Force, Siemens Healthcare, Forchheim, Germany). Images were acquired in DECT mode with the following acquisition parameters: tube A 90 kV, reference current-time product of 95 mAs per rotation; tube B Sn150 kV with tin filter, 59 mAs per rotation. Rotation time was 0.5 s, the pitch was set to 1.0, and collimation was 2 × 192 × 0.6 mm. Scans were acquired using attenuation-based tube current modulation (CARE Dose 4D, Siemens). Image acquisition during the venous phase of contrast enhancement started automatically 70 s after contrast material injection in craniocaudal direction and inspiratory breath-hold. A nonionic contrast agent (Imeron 350, Bracco, Milan, Italy) at a dose of 1.2 mL per kilogram body weight (maximum of 120 mL) was injected with a flow rate of 2 mL/s through a peripheral vein of the forearm. CT dose index ($CTDI_{vol}$) and the dose length product (DLP) of each patient were recorded for an estimation of the DECT radiation dose.

2.3. DECT image reconstruction

All DECT datasets were post-processed on a commercially available 3D multi-modality workstation (syngo.via, version VA30A, Siemens) using a dedicated soft tissue convolution kernel (Qr40, Siemens) and iterative reconstruction technique (ADMIRE, Siemens; strength level, 3). Standard image series reconstructed with linear blending technique (M_0.6) were automatically calculated by merging 60% of the low-kV with 40% of the high-kV spectrum to emulate routine single-energy 120-kV acquisition [10,14,15]. The traditional VMI and noise-optimized VMI+ series were reconstructed at 40–100 keV levels in 10-keV increments [13]. According to prior studies, images at higher energy levels beyond 100 keV were not calculated, as the iodine attenuation can be expected to be too low [16]. All series were reconstructed as axial and coronal reformat images, with a thickness of 3 mm and increment of 1.5 mm, respectively.

2.4. Quantitative image analysis

Quantitative image analysis was performed on a dedicated workstation (syngo.via, Siemens) by a radiologist with 3 years of experience in CT imaging. Signal attenuation in mean Hounsfield units (HU) was measured in cutaneous malignant melanomas, as well as in histologically-proven regional lymph node, subcutaneous and in-transit metastases. Measurements were performed by placing a circular region-of-interest (ROI) centrally in the tumor lesion (100 mm^2). Focal areas of tumor necrosis were avoided. Additional measurements were performed within subcutaneous fat (250 mm^2) to assess image contrast and image noise. Measurements were performed two times and averaged to ensure data consistency and high measurement accuracy.

The following formulas were used for calculating signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) values, according to previous studies [14,17,18]:

$$SNR = HU\ (lesion) / SD\ (fat)$$

$$CNR = (HU\ (lesion) - HU\ (fat)) / SD\ (fat)$$

2.5. Qualitative image analysis

Qualitative image analysis was performed by 3 radiologists with 4–6 years of experience in CT imaging. All images were independly reviewed and the reviewers were blinded to the DECT image reconstruction technique. To reduce recall bias, all image series were evaluated in random order and separately in different sessions. During each readout session, only a single, randomly chosen image series from each patient was evaluated. There was a time interval of at least 2 weeks between each readout session and the observers had no influence on the order of images. Readers could freely modify the preset window settings (width, 400 HU; level, 100 HU) as low-keV VMI+ reconstructions may require different width and level settings to improve the visualization and contrast conditions [19]. Furthermore, the observers were aware that all patients received treatment for cutaneous malignant melanoma. Image series were rated using 5-point Likert scales under the following aspects [11,13]: Overall image quality (ranging from 1 = poor image quality with substantial image noise to 5 = excellent image quality with no perceivable noise), lesion delineation (ranging from 1 = no visual delineation to 5 = perfect delineation of contours), and image noise (ranging from 1 = extensive image noise to 5 = absence of noise).

2.6. Statistical evaluation

Analyses were performed using dedicated statistical software (MedCalc Statistical Software Version 17.2, MedCalc Software bvba, Ostende, Belgium). Continuous variables were expressed as mean ± standard deviation. Ordinal variables were reported as median with ranges. A P value < 0.05 was considered to indicate a statistically significant difference. The Kolmogorov-Smirnov test was applied to test for normality of data distribution. Analysis of variance (ANOVA) was performed for quantitative values. Bonferroni correction for multiple comparisons was applied for P-values and confidence intervals [20,21]. In case of non-normal distribution, comparisons were performed using the Wilcoxon matched-pairs test.

Interobserver agreement among the three reviewers was evaluated by calculating intraclass correlation coefficient (ICC) (two-way model, single measure) with 95% confidence intervals [CI] and interpreted as follows [22]: ICC < 0.40 = poor agreement, ICC 0.40–0.59 = fair agreement, ICC 0.60–0.74 = good agreement, ICC