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Effect of radiation dose reduction and iterative reconstruction on computer-aided detection of pulmonary nodules: Intra-individual comparison

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ABSTRACT

Objective: To evaluate the effect of radiation dose reduction and iterative reconstruction (IR) on the performance of computer-aided detection (CAD) for pulmonary nodules.
Methods: In this prospective study twenty-five patients were included who were scanned for pulmonary nodule follow-up. Image acquisition was performed at routine dose and three reduced dose levels in a single session by decreasing mAs-values with 45%, 60% and 75%. Tube voltage was fixed at 120 kVp for patients ≥80 kg and 100 kVp for patients <80 kg. Data were reconstructed with filtered back projection (FBP), iDose^4 (levels 1,4,6) and IMR (levels 1–3). All noncalcified solid pulmonary nodules ≥4 mm identified by two radiologists in consensus served as the reference standard. Subsequently, nodule volume was measured with CAD software and compared to the reference consensus. The numbers of true-positives, false-positives and missed pulmonary nodules were evaluated as well as the sensitivity.
Results: Median effective radiation dose was 2.2 mSv at routine dose and 1.2, 0.9 and 0.6 mSv at respectively 45%, 60% and 75% reduced dose. A total of 28 pulmonary nodules were included. With FBP at routine dose, 89% (25/28) of the nodules were correctly identified by CAD. This was similar at reduced dose levels with FBP, iDose^4 and IMR. CAD resulted in a median number of false-positives findings of 11 per scan with FBP at routine dose (93% of the CAD marks) increasing to 15 per scan with iDose^4 (95% of the CAD marks) and 26 per scan (96% of the CAD marks) with IMR at the lowest dose level.
Conclusion: CAD can identify pulmonary nodules at submillisievert dose levels with FBP, hybrid and model-based IR. However, the number of false-positive findings increased using hybrid and especially model-based IR at submillisievert dose while dose reduction did not affect the number of false-positives with FBP.

1. Introduction

Lung cancer screening in high-risk individuals reduces mortality [1]. Therefore, both European and American guidelines recommend lung cancer screening implementation [2,3]. Since 23–53% of patients in lung cancer screening trials have pulmonary nodules at baseline which require follow-up, this will lead to an increased workload for radiologists [4,5]. Also in routine practice incidental pulmonary nodules and pulmonary metastases are a common finding. Computer-aided detection (CAD) can assist radiologists in the identification of pulmonary nodules in screening as well as routine care in patients with and without a known malignancy. Dedicated software tools are available that automatically identify and annotate potential nodules [6]. CAD combined with assessment by a radiologist improves the sensitivity for pulmonary nodule detection compared to assessment by a radiologist alone [6–8]. However, CAD can also lead to an increased number of false positive findings [9].

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Increased awareness of the harmful effects of radiation exposure has led to technical innovations to reduce the radiation dose associated with CT examinations [10]. Iterative reconstruction (IR) computationally decreases image noise compared to the conventional reconstruction technique filtered back projection (FBP) making radiation dose reduction possible. A phantom study investigated the effect of application of a hybrid IR technique on CAD and concluded that IR did not affect CAD performance [6]. However, results may be different in patients and for more advanced model-based IR techniques because these are associated with a smoother appearance of anatomical structures in which details can be missed [11]. It is unknown if the use of these advances IR techniques also affects the performance of CAD for pulmonary nodules, because current CAD is trained with FBP images. Therefore, in this patient study we investigated the effect of dose reduction and hybrid and model-based IR on the performance of CAD for pulmonary nodules.

2. Methods

Our local institutional review board approved this prospective study (NL46146.041.13). Inclusion criteria were an age of 50 years or older (1) and scheduled for a follow-up chest CT for known pulmonary nodules (2). Exclusion criterion was concomitant participation in another study with x-ray exposure.

2.1. Computed tomography

All CT acquisitions were performed on a 256-slice Brilliance iCT system (Philips Healthcare, Best, The Netherlands). CT data were acquired in full inspiration and without contrast injection. After a scout image, the routine dose scan was acquired, followed by three reduced dose scans. Every scan was acquired during a different breath hold and all scans within a patient were performed with the same scan length. Exposure settings were 60, 33, 24 and 15 mAs combined with a tube voltage of 100 kV for patients with a weight below 80 kg and 120 kV for patients with a weight above 80 kg. Reconstructed slice thickness was 1 mm. All images were reconstructed with FBP, a hybrid IR algorithm (iDose^4, Philips Healthcare, Best, The Netherlands) and a prototype version of an iterative model-based algorithm (IMR, Philips Healthcare, Best, The Netherlands). For iDose^4 levels 1, 4 and 6 (kernel filter C) were used and for IMR levels 1, 2 and 3 (kernel filter Body Routine). It is not possible to use kernel filter C for IMR, therefore we used vendor recommended kernel filter Body Routine.

For each scan the volumetric CT dose index ($CTDI_{vol}$) and the dose-length product (DLP) were recorded. Effective dose was determined by multiplying the DLP with the conversion factor for the chest (0.0145 mSv/(mG × cm) for 120 kV and 0.0144 mSv/(mG × cm) for 100 kV) [12].

2.2. Computer-aided detection

As a reference, solid non-calcified pulmonary nodules with a diameter of 4 mm or more were identified on routine dose FBP reconstructions by two radiologists independently. In case of discrepancy the case was discussed to reach consensus. Commercially available software (IntelliSpace Portal, V6.0.1.20250, Lung Nodule Assessment, Philips Healthcare, Best, The Netherlands) was used for CAD of pulmonary nodules. CAD automatically identified pulmonary nodules with a size of 4–30 mm. These were subsequently inspected by one observer and compared with the reference nodules detected by the two radiologists. The numbers of true-positives, false-positives and missed (false-negative) pulmonary nodules were determined. Sensitivity was calculated for each reconstruction technique at each dose level by dividing the total number of true pulmonary nodules detected by CAD by the total number of true nodules present.

2.3. Statistical analysis

SPSS (version 20.0, IBM, New York, United States) was used for statistical analysis. All measurements were compared to the reference standard namely FBP at routine dose. Data were compared using the Friedman test and the Wilcoxon signed rank test was used for post hoc analyses. A p-value below 0.05 was considered statistically significant for the Friedman test and a Bonferroni correction was made for the post hoc Wilcoxon test resulting in a p-value of 0.007. Values are given as medians with interquartile ranges (IQR) unless otherwise stated.

3. Results

Twenty-five patients were included. In two patients IMR data were accidentally deleted before the IMR reconstructions were made and in one patient the lowest dose scan was not performed. These three patients were excluded from further analysis. Therefore, data of 22 patients was analyzed.

The median age was 66 (IQR 60–72) years and half of the patients were female. Median BMI was 28.6 (IQR 26.0–31.4) kg/m^2 and in twelve patients the ≥80 kg protocol was used. Radiation dose characteristics are provided in Table 1. Effective dose was 2.2 (1.4–2.4) mSv at routine dose and 1.2 (0.8–1.3), 0.9 (0.5–1.0) and 0.6 (0.3–0.6) mSv at reduced dose levels respectively.

3.1. Pulmonary nodules

Nine patients did not have pulmonary nodules. The remaining patients had 1 nodule (5 patients), 2 nodules (5 patients), 3 nodules (1 patient) or 5 nodules (2 patients). In total 28 nodules were included with a median diameter of 7.0 (5.1–8.7) mm and median volume of 177 (70–346) mm^3 as measured on the reference dose scan reconstructed with FBP.

3.2. Computer-aided detection

The CAD system read and analyzed all datasets successfully. Fig. 1 shows the user interface of the CAD system while Fig. 2 shows an example of a nodule detected at different dose levels with FBP, iDose^4 and IMR. The total number of true-positive, false-negative and false-positive nodules is provided in Table 2. Sensitivity with FBP at routine dose was 89% (25/28) while 93% (353/381) of the CAD marks were incorrect. The sensitivity was the same with iDose^4 level 1 and 4 and all IMR levels while iDose^4 level 6 resulted in a slightly higher sensitivity of 93% (26/28) at routine dose. At 45% and 60% reduced dose FBP and iDose^4 and IMR level 3 yielded the same or increased sensitivity while sensitivity slightly decreased with IMR level 1 and 2 to 82% (23/28). At the lowest dose level, sensitivity increased to 93% (26/28) for all reconstructions except iDose^4 level 1. None of the differences in sensitivity were significant. Six pulmonary nodules were missed on one or more reconstructions (Fig. 3). These nodules had a median diameter of 7.2 (range 4.5–21.0) mm and a volume of 195.2 (range 48.3–4874.9) mm^3. Three of the missed pulmonary nodules were localized adjacent to blood vessels or the pleural wall. Two missed pulmonary nodules were very small (5 mm) while one missed pulmonary nodule was extremely large (21 mm), although the CAD software should be able to detect pulmonary nodules up to 30 mm.

The number of false-positive nodules identified with CAD was high: at routine dose reconstructed with FBP, 93% (353/378) of the CAD marks were incorrect. At reduced dose levels this remained 93% with FBP, 92–95% with iDose^4 and 94–96% with IMR.