Image quality, effective and organ dose to the breast in females undergoing pulmonary MDCT angiography: comparison of filtered back projection and iterative image reconstruction

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Purpose

The radiation dose resulting from medical exposure rises in the population continuously. It has increased several times within the last three decades and reached the level of natural radiation background in some developed countries, e.g. USA [1]. Computed tomography is the major contributor, accounting for more than two thirds of the entire cumulative medical exposure [2].

To reverse this unfavourable trend attributed to steadily increasing number of CT procedures, adoption of adequate precautions is of utmost importance. Among these, an innovative technique of iterative reconstruction of CT image seems promising as it significantly reduces image noise and therefore allows radiation exposure reduction by up to tens of percent [3, 4].

The purpose of the study is to compare image characteristics, effective and organ dose to the female breast in pulmonary multidetector CT angiography (MDCTA) using either standard filtered back projection (FBP) technique or iterative reconstruction in image space (IRIS).
Methods and Materials

Study population

Pulmonary MDCTA for ruling out pulmonary embolism was prospectively performed in 110 consecutive females (age 18 - 70 years). The scans were reconstructed with standard FBP (n=55) and, after CT reconstruction software upgrade, with IRIS (n=55).

Study protocol

Scans were performed on a multidetector single source MDCT scanner from the level of jugulum to the posterior costophrenic recesses with following parameters: collimation 64 x 2 x 0.6 mm, tube voltage 100 kV, quality reference mAs value 120 (FBP) and 80 (IRIS), pitch factor of 1.4, rotation time of 0.3 seconds, reconstructed slice thickness 1 mm, automatic 4D dose modulation switched on in order to balance image quality and radiation dose throughout the scans of subjects with widely variable attenuation profile and body mass index (BMI).

Contrast agent with concentration of 400 mg/ml of iodine was injected by a dual head power injector with a flow rate of 4 ml/s (3 ml/s in cases of limited venous access quality). Bolus tracking threshold was set at 90 HU (subjects<40 years old) or 160 HU (subjects ≥ 40 years old) with a region of interest (ROI) placed within the pulmonary trunk.

Radiation dose

Effective doses and organ doses to the breast were calculated from CT dose index (CTDItvol, mGy) and dose length product (DLP, mGy.cm) values utilizing ImPACT software (Impact, London).

Quantitative parameters

Both FBP and IRIS scans reconstructed with 1 mm slice thickness were quantitatively assessed for adequate pulmonary artery enhancement and image noise by measuring mean attenuation value and standard deviation of Hounsfield units (HU) in a 2.5 cm² ROI placed within the main pulmonary artery.

Qualitative parameters

Qualitative visual assessment of the scans was independently performed by two radiologists with 17 and 10 years of cross-sectional imaging experience who were blinded to the type of CT image reconstruction, using a visual analogue scale:

1 = very low noise, optimal diagnostic quality

2 = low noise, good diagnostic quality
3 = increased noise, diagnostic quality
4 = high level noise, limited diagnostic quality
5 = unacceptable noise, non-diagnostic scan

Statistics

Descriptive parameters of the study population and image reconstruction techniques were statistically compared using t-test or non-parametric tests (Mann-Whitney, Kolmogorov-Smirnov). Qualitative parameters were compared using Fisher's exact test for contingency tables. Interobserver agreement was evaluated by kappa reliability test.
Results

**Study population**

Of 110 subjects enrolled into the study, 27 subjects were excluded from evaluation due to deviation from the protocol (presence of metallic/respiratory/motion induced artifacts, upper extremities placed alongside the trunk). Thus, a total of 34 FBP and 49 IRIS scans were available for evaluation.

The groups of FBP and IRIS scans showed no statistically significant differences when evaluating median attenuation values measured within the pulmonary artery (p=0.64), craniocaudal coverage of scans (p=0.08), or body mass index of the subjects (p=0.10).

**Radiation dose**

The average CTDIvol yielded 4.30 for FBP and 3.56 for IRIS, respectively (17.2% decrease). The average DLP was 133.2 (FBP) and 116.4 (IRIS), respectively (12.6% decrease). The average effective dose was 2.70±0.54 mSv (FBP) and 2.30±0.64 mSv (IRIS), respectively (14.8% decrease). The average organ dose to the breast decreased from 5.1±1.1 mGy (FBP) to 4.3±1.1 mGy (IRIS, 15.7% decrease).

**Quantitative parameters**

Additionally, image noise levels were significantly lower (p<0.001) in the IRIS group (median 19.2 HU) compared to the FBP group (median 23.0 HU).

Major study results are summarized in Table 1.

**Qualitative parameters**

A total of 28.6 % of IRIS scans and 11.8 % of FBP scans were qualitatively marked as optimal: mark 1 on visual scale (Fig. 1, 2). On the contrary, 16.1 % of FBP scans and 3.0 % of IRIS scans were of limited diagnostic quality: mark 4 (Fig. 3, 4). No non-diagnostic scans (mark 5) were noted in either group. According to Fisher's exact test, IRIS scans were rated significantly better in terms of image quality (p=0.03).

Interpretative agreement between the two readers was excellent (kappa=0.86; kappa's standard error=0.07).

**Table 1**

<table>
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<tr>
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<th>n</th>
<th>BMI median</th>
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<th>PA lumen</th>
<th>noise [SD] median</th>
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</table>

**Major study results**

(BMI - body mass index; PA - pulmonary artery; SD - standard deviation; NA - not applicable; NS - not significant)
Fig. 1: FBP reconstructed 1 mm thin sections with optimal diagnostic quality (mark 1). Very low image noise with homogenous vessel lumen opacity (mean PA density of 547 HU, noise [SD] 17 HU). Excellent delineation of segmental and subsegmental (arrow) arterial branches.

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Fig. 2: IRIS reconstructed 1 mm thin sections with optimal diagnostic quality (mark 1) in a patient with pulmonary embolism. Very low image noise with homogenous vessel lumen opacity (mean PA density of 496 HU, noise [SD] 17 HU). Excellent homogeneity and delineation of segmental and subsegmental arterial branches, convincing evidence of multiple non-occlusive subsegmental emboli (arrows).

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Fig. 3: FBP reconstructed 1 mm thin sections with limited diagnostic quality (mark 4) in an obese subject with BMI of 31. High level of image noise with marked vessel lumen inhomogeneity which might simulate filling defects (arrow). Mean PA density of 321 HU, noise [SD] 39 HU.

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Fig. 4: IRIS reconstructed 1 mm thin sections with limited diagnostic quality (mark 4) in an obese subject with BMI of 38. High level of image noise with marked vessel lumen inhomogeneity which might simulate filling defects (arrow). Mean PA density of 334 HU, noise [SD] 42 HU.

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Conclusion

With almost exponential rise of number of CT procedures performed worldwide annually, the need for standardization, optimization, and stringent adherence to ALARA ("as low as reasonably achievable") principles is stronger than ever. Nonetheless, even recent publications indicate that there is substantial variance of doses applied at the same types of CT procedures at different institutions as well as significant potential for reducing radiation dose in routine CT examinations [5, 6]. A multicentric study from California estimates that one in 330 females undergoing MDCTA for ruling out pulmonary embolism at the age of twenty will develop a radiation induced cancer. The study also shows great deal of variance of effective doses applied at pulmonary MDCTAs among four institutions: median of 10 mSv, range 2 - 30 mSv [5].

Iterative reconstruction of CT image offers significant image noise reduction when compared to FBP, therefore allowing CT acquisitions of comparable image quality with lower radiation dose. The advantages of iterative image reconstruction for dose savings in chest CT studies were recently demonstrated in several innovative studies [3, 4, 7, 8].

The average effective dose in our unselected female population (with BMI widely ranging from 15 to 48) was 2.7 mSv in the FBP group, i.e. at the lower end of the dose range indicated in [5, 6, 9]. Thus it can be inferred that our institutional protocols were optimized according to ALARA principles. Our results show that even in the settings of optimized FBP based protocols, both image quality improvements and radiation dose savings are feasible by applying techniques of iterative reconstruction which, in our population, reduced the average effective dose by 15 % to 2.3 mSv. Similarly, the organ dose applied to the female breast decreased by 15.7 % to 4.3 mGy in the IRIS group, without introducing streak artifacts reported when using bismuth breast shielding [10, 11], without compromising objective or subjective image quality (optimal scan quality was even noted 2.5 times more frequently in the IRIS group than in the FBP group). This desirable radiation saving effect is underlined by the fact that pulmonary MDCTA is often performed in young females (31 % of subjects in our study group were not older than 40 years). Also, overall breast tissue radiosensitivity as well as the fact that the breast is exposed to the primary beam in almost all MDCTA studies should be taken into consideration.

To our knowledge, this is the first study which evaluates the potential benefit of iterative reconstruction of pulmonary MDCTA in terms of quantifying organ radiation dose applied to the female breast. Our results show that iterative reconstruction enables further reduction of both effective and breast organ dose in this procedure. Moreover, iterative reconstruction offers improvements in image noise and visual perception of the scans with reduced radiation dose, thus opening potential for further dose reduction.
References


Personal Information

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