CT Pulmonary Angiography (CTPA) as a sub-mSv modality: dose reduction using new iterative reconstruction algorithms

This article summarizes a recent evaluation of a new iterative reconstruction algorithm for the detection/rule-out of pulmonary embolism (PE) in ultra-low dose computed tomography pulmonary angiography (CTPA).

The results show that by using a next generation iterative reconstruction algorithm “Iterative Model Reconstruction” (IMR) for the detection of PE, a reduction in dose of up to 75% is possible in CTPA, while maintaining full diagnostic confidence. This would result in a mean effective dose of below 1.0 mSv for CTPA.

Computed tomography pulmonary angiography (CTPA) is the most commonly used imaging modality to confirm/rule-out suspected pulmonary embolism (PE) [1-3]. CTPA is available at all times in most hospitals, can be performed quickly and is relatively cost efficient. With recent improvements in CT technology, high diagnostic accuracy can be achieved, with sensitivities of up to 92% and specificities of up to 95% [4].

However, CTPA involves a high radiation exposure with a currently estimated average dose of 10.7 mSv [5]. Thus it should be noted that the use of CTPA is limited in pregnant women, as well as in patients with chronic kidney failure and/or iodine allergy. In such patients, the use of CTPA must be considered carefully; it may be that eventually CTPA is not possible in these cases.

Over the last few decades, the number of CT scans carried out worldwide increased dramatically: in the United States the number of CT scans grew rapidly from approximately 3 million in 1980 to about 62 million in 2006 [6]. This has resulted in a corresponding increase in collective radiation exposure, which has been associated with a potentially increased lifetime risk of malignancy and a danger of damage to the gametes, especially with younger or pregnant patients [6, 7]. In addition CTPA there is a substantial radiation exposure to the breast; ionizing radiation is an established risk factor for breast cancer [8].

For all these reasons, methods for reducing radiation dose are highly desirable, particularly for younger patients. Various techniques for dose reduction have been developed and partially implemented in daily clinical routine, following the principle of "as low as reasonably achievable" (ALARA) [9]. In addition to the use of shielding techniques, reduction of anatomical scan coverage and new methods such as z-axis modulation, the dose can be reduced by lowering tube peak kilo voltage (kVp) or tube current (mA). [10]. Several studies have shown that acceptable image quality of CTPA can be maintained when tube voltage is reduced to 100 kVp or even 80 kVp, resulting in significantly lower radiation exposures [11, 15]. However, reduced tube voltage leads to higher image noise, especially in obese patients. To compensate for image noise, higher tube currents are needed, leading to only limited reduction of radiation dose [12].

In order to further decrease radiation dose, additional reduction of tube current must be aimed for. Depending on the individual patient's habitus, different tube currents are needed to obtain suitable image quality. However, highly reduced tube current can lead to impaired image quality, making missed diagnoses more likely [13, 14].

Advances in processing power and the development of new and faster algorithms have enabled wide-spread clinical use of iterative reconstruction methods. These iterative reconstruction algorithms make improvements in image quality and consequent reduction of radiation dose possible, even in obese patients [15, 17, 18]. Iterative reconstruction has been widely introduced into clinical routine over the last five years and first generation iterative algorithms have already led to a significant reduction of image noise in comparison to filtered back projection (FBP) reconstruction [16].

STUDY DESIGN
In this study a new iterative reconstruction algorithm was compared to a first-generation iterative reconstruction algorithm (iDose) and standard filtered back projection (FBP) at different simulated tube current levels [19].
The objective of the study was to evaluate the diagnostic performance of a new generation iterative reconstruction algorithm (IMR) in low and ultra-low dose CTPA with a particular focus on image quality and diagnostic confidence in the diagnosis of PE.

Sixteen patients with PE were enrolled into this single centre study. PE was subclassified as central, segmental, or subsegmental. Multiple localizations were also possible.

All patients were examined using a 256-slice multidetector CT (Brilliance iCT; Philips Healthcare) using a standard CTPA protocol. The CTPA raw data were then used to simulate CTPA scans with reduced tube currents, resulting in dose levels (DL) of 50%, 25%, 12.5%, 6.3% and 3.1% of the original dose. All other imaging parameters remained identical. All CTPA images so obtained (i.e. tube current levels of 100% - 3.1%) were then reconstructed with FBP, iDose, and IMR, resulting in a total of 288 datasets (6 different levels of tube current, 3 different algorithms, 16 patients).

Each data set was independently evaluated by two blinded radiologists according to the following criteria: image noise, classic artefacts, ring artefacts, image quality, diagnostic confidence in detection of central and peripheral PE as well as overall diagnostic confidence and artificial image appearance. The radiologists carrying out the rating were asked to evaluate central, segmental and subsegmental pulmonary arteries in every data set as positive or negative for PE. PEs in multiple localizations were possible. As there is no gold standard for the detection of PE, the clinical report, the radiologists carrying out the rating, and artificial image appearance were used to determine the correctness of ratings. In order to measure image quality objectively, two contrast-to-noise ratios (CNR) were determined: one for the main pulmonary artery as a central vessel (central contrast to noise radio – cCNR) and one for a segmental artery as a peripheral vessel (peripheral contrast to noise ratio - pCNR).

RESULTS:
The mean effective dose for all examinations was 3.6 ± 2.9 mSv.

For images reconstructed with iDose and IMR, the median subjective image quality was higher than that of images reconstructed with FBP at all dose levels from 100% to 12.5% DL. At a DL of 3.1%, median image quality was 1 (i.e. unacceptable for diagnostic purposes) for all algorithms. The median image quality was higher after reconstruction with IMR than after reconstruction with iDose at DL of 6.3% and 25%.

Using iDose and IMR reconstruction, significantly higher diagnostic confidence could be obtained than with FBP reconstruction (p < 0.01). This conclusion was true for all divisions of PE (central, peripheral, overall) and to all dose levels.

At lower dose levels, IMR-images produced a higher median diagnostic confidence than iDose images (higher median in IMR-images than in iDose-images at 12.5% DL for all divisions of PE and at 6.3% DL for central and peripheral PE).

In IMR-images the median diagnostic confidence in the detection of PE was 4 (completely confident) for central PE at DL of 25%, 50% and 100%. On the basis of the full-dose images, no PE (central, segmental, and subsegmental) was missed by either rating radiologist in IMR-reconstructed images at dose levels of 12.5% to 100%, resulting in a sensitivity of 100%. The same conclusion was found with iDose at dose levels of 25%-100%. With FBP reconstruction, only at 100% DL was every PE identified. With the use of FBP-reconstruction at 12.5% DL, only 35% of all central, 23% of all segmental and 19% of all subsegmental PEs could be identified.

At all dose levels, cCNR and pCNR were significantly better in IMR-images than in iDose and FBP-images (p < 0.01). In addition, cCNR in IMR-images at DLS of 50%, 25% and 12.5% was significantly better than in iDose-images at 100% DL (p < 0.05).

SUMMARY AND OUTLOOK:
Over the last few years, it has been shown that the use of iterative reconstruction algorithms has made possible significant dose reduction via reduced tube-current and tube-voltage [13]. However, even further reduction of radiation exposure is desirable particularly as CTPA is frequently used in clinical routine. As a reduction of tube voltage below 80 kVp is not reasonable due to the k-edge of iodine, further reduction of radiation dose has to be obtained by reducing tube current.

The results of the present study show...
Radiation dose reduction can be dramatically reduced through the application of new iterative reconstruction algorithms. In our study, IMR, a second generation iterative reconstruction algorithm, provided excellent diagnostic confidence in the detection of PE even in ultra-low-dose images acquired with a simulated mean effective dose of only 0.9 mSv. However, according to the ALARA principle, dose should not be lowered to the lowest possible value but only to the value at which a very high diagnostic confidence is guaranteed.

We suggest a dose reduction of no greater than 75% since, down to this dose level the diagnostic confidence is guaranteed. In the future, it can be foreseen that further radiation dose reduction can be achieved by the combination of new technologies such as spectral photoncounting CT [20] or sparse sampling CT in combination with iterative reconstruction algorithms.

CONCLUSION
Using next generation iterative reconstruction algorithms such as IMR, the radiation dose for CTPA examinations can be lowered dramatically, while providing suitable image quality and diagnostic confidence even in sub-mSv images.

REFERENCES: