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Achievable dose reduction using iterative reconstruction for chest computed tomography: A systematic review

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ABSTRACT

Objectives: Iterative reconstruction (IR) allows for dose reduction with maintained image quality in CT imaging. In this systematic review the reported effective dose reductions for chest CT and the effects on image quality are investigated.
Methods: A systematic search in PubMed and EMBASE was performed. Primary outcome was the reported local reference and reduced effective dose and secondary outcome was the image quality with IR. Both non contrast-enhanced and enhanced studies comparing reference dose with reduced dose were included.
Results: 24 studies were included. The median number of patients per study was 66 (range 23–200) with in total 1806 patients. The median reported local reference dose of contrast-enhanced chest CT with FBP was 2.6 (range 1.5–21.8) mSv. This decreased to 1.4 (range 0.4–7.3) mSv at reduced dose levels using IR. With non contrast-enhanced chest CT the dose decreased from 3.4 (range 0.7–7.8) mSv to 0.9 (range 0.1–4.5) mSv. Objective mage quality and diagnostic confidence and acceptability remained the same or improved with IR compared to FBP in most studies while data on diagnostic accuracy was limited.
Conclusion: Radiation dose can be reduced to less than 2 mSv for contrast-enhanced chest CT and non contrast-enhanced chest CT is possible at a submillisievert dose using IR algorithms.

1. Introduction

The rapid increase in the number of computed tomography (CT) scans has raised concerns about the safety of CT examinations and the associated radiation exposure [1]. As lung cancer screening with chest CT is now implemented in the USA a further increase in the number of chest CT scans is anticipated [2]. To reduce radiation dose several options are available including automatic tube current and potential selection and, more recently, iterative reconstruction (IR) [3,4].

Although the concept of IR has been around for decades these techniques were not widely used due to a lack of computational power. These limitations have been overcome and all major CT vendors now have IR algorithms available for clinical use. The traditionally used CT reconstruction method, filtered back projection (FBP), is fast but leads to image deterioration when radiation dose is lowered. IR involves multiple iterations leading to improved image quality even at a reduced dose. Most IR algorithms are not fully iterative but use a combination of IR and FBP, also called hybrid IR. Two vendors developed more advanced algorithms approaching true IR, also known as model-based IR. Previously the technical principles of IR have been explained in detail [5]. A brief overview of the different available IR techniques is presented in Table 1.

The potential of IR for dose reduction in chest CT has been investigated in a substantial number of studies. Interestingly, even chest CT examinations at a radiation dose approaching conventional chest X-rays have been reported using IR [6,7]. This may open the possibility to replace radiography with low dose CT for certain indications [8]. However, it is not clear yet to which extent the radiation dose can be reduced routinely by using IR for chest CT. Therefore the reported achievable dose reductions of studies using IR in chest CT were evaluated. Furthermore, the reported effects of dose reduction and IR on image quality were assessed.

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Table 1
Overview of different available iterative reconstruction techniques.

Abbreviation	Vendor	Full name	Type
ASIR	GE	Adaptive statistical iterative reconstruction	Hybrid
MBIR-veo	GE	Model-based iterative reconstruction	Model-based
iDose	Philips	iDose	Hybrid
IMR	Philips	Iterative model reconstruction	Model-based
ADMIRE	Siemens	Advanced modeled iterative reconstruction	Hybrid
IRIS	Siemens	Iterative reconstruction in image space	Hybrid
SAFIRE	Siemens	Sinogram-affirmed iterative reconstruction	Hybrid
AIDR	Toshiba	Adaptive iterative dose reduction	Hybrid
AIDR 3D	Toshiba	Adaptive iterative dose reduction 3D	Hybrid

2. Material and methods

2.1. Search

MEDLINE and EMBASE were systematically searched by combining synonyms for 'IR techniques' and 'CT' with English language restriction. The full search syntax is provided in the Appendix A. Duplicates were removed and reference lists of included articles and review articles were searched for additional articles.

2.2. Inclusion and exclusion criteria

Two authors screened all articles (AH and MW). In case of discrepancy consensus was reached between authors. Original research articles concerning chest CT with IR in adults investigating routine and reduced dose levels were included. All indications for chest CT were included. Ex-vivo, in-vitro, animal and pediatric studies were excluded. Studies combining chest CT with abdominal CT were excluded, because the primary outcome was the effective dose of chest CT alone. Reviews as well as case reports (<5 patients) were excluded.

2.3. Data extraction

Data, including first author, journal, publication date, title, study design, participant characteristics, scan indication, reconstruction technique, type of scan, type of CT system, and reported dose and image quality measurements were extracted to a standardized sheet.

Primary outcome was the effective dose, which was defined as the dose-length product (DLP) times the conversion factor for chest CT (0.014 mSv/(mGy*cm)) [9,10]. In case the effective dose was not provided and not computable the corresponding author was contacted. If a different conversion factor was used, the effective dose was recalculated. Secondary outcome was the influence of IR on objective and subjective image quality. This was specified as lower (i.e. deteriorated) image quality, no change in image quality or improved image quality compared to FBP. The most favorable outcome was used in case different IR levels were studied. Objective image quality is measured using signal-to-noise ratio, contrast-to-noise ratio or noise. Different methods can be used to measure subjective image quality. If the study reported that the difference in objective and/or image quality was significant between FBP and IR, this was defined as deteriorated or improved.

2.4. Statistical analysis

SPSS (version 20.0 for Microsoft Windows) was used for statistical analyses. Correlations between effective dose and publication year were tested by Pearson's correlation test. A p-value below 0.05 was considered statistically significant.

3. Results

3.1. Study selection

In total 2556 articles were identified. After removal of duplicates 1616 articles were screened on title and abstract. Fifteen-hundred-eighty-six articles were excluded because the articles did not investigate IR for CT (n = 1,338), did not evaluate chest CT (n = 194), were not based on in-vivo data (n = 16), concerned pediatric studies (n = 2), studied combined chest CT with abdominal CT (n = 21) or investigated only a single dose level (n = 15). A flowchart is provided in Fig. 1. Corresponding authors of seven articles were contacted because reported information about radiation dose was insufficient [11–17]. One author provided the requested dose information [17] and the remaining six articles were excluded due to insufficient information about radiation dose. Therefore ultimately 24 studies were included.

3.2. Baseline characteristics

Baseline characteristics are provided in Table 2. Patients in the included articles had a median age of 62 years (not reported in 3 studies), median BMI of 24 kg/m^2 (not reported in 9 studies) and 46% was female (not reported in 1 study). The median number of patients per study was 66 (range 23–200) with in total 1806 patients. Studies were published in 2010 (n = 1), 2011, (n = 3), 2012 (n = 6), 2013 (n = 10) and 2014 (n = 4). Different IR techniques were used: ASIR (n = 11), SAFIRE (n = 5), iDose^4 (n = 1), IRIS (n = 5), MBIR (n = 6), AIDR (n = 1) and AIDR 3D (n = 1). Six studies used two different IR techniques namely AIDR and AIDR 3D [18] and ASIR and MBIR [6,19–22].

Fifteen studies (63%) compared imaging at a local reference dose with reduced dose imaging in the same patient. Comparison of different dose levels in the same patient was achieved by using data from only one detector of a dual source CT scanner (n = 2) [24,25], using a previously made scan (n = 2) [17,26], comparing the scan non contrast-enhanced scan with the contrast-enhanced scan (n = 1) [27] or by making one (n = 7) [6,18,19,22,28–30] two (n = 2) [20,21] or four (n = 1) [31] additional scans for research purposes. The indication for chest CT varied widely. Two studies solely investigated lung nodule follow-up scans and lung cancer screening scans [29,30]. Most studies included patients with different indications for chest CT like suspected pulmonary infection, oncology staging and surveillance or an abnormality on chest X-ray.

Nine studies reported the dose of contrast-enhanced CT, 13 studies of non contrast-enhanced CT and two studies [17,24] investigated both contrast-enhanced and non contrast-enhanced CT.

3.3. Radiation dose

The median reported local reference dose of contrast-enhanced chest CT with FBP was 2.6 (range 1.5–21.8) mSv. This decreased to 1.4 (range 0.4–7.3) mSv at reduced dose levels using IR. The median percentage of dose reduction achieved with IR was 50