Review article – The impact of Sinogram-Affirmed Iterative Reconstruction on patient dose and image quality compared to filtered back projection: a narrative review

Abdulfatah Ahmed[a], André Garcia[b], Astrid Bakker[c], David Tomkinson[a], Julie Salamin[d], René de Lange[c], Sergey A. Buyvidovich[e], Tina Sohrabi[e], Alexandre Dominguez[d], Cosmin Campeanu[d], Paul Plasman[c]

a)   School of Health Sciences, University of Salford, Manchester, United Kingdom
b)   Lisbon School of Health Technology (ESTeSL), Polytechnic Institute of Lisbon, Portugal
c)   Department of Medical Imaging and Radiation Therapy, Hanze University of Applied Sciences, Groningen, The Netherlands
d)   Haute École de Santé Vaud – Filière TRM, University of Applied Sciences and Arts of Western Switzerland, Lausanne, Switzerland
e)   Department of Life Sciences and Health, Radiography, Oslo and Akershus University College of Applied Sciences, Oslo, Norway

KEYWORDS

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ABSTRACT

Objective: Summarize all relevant findings in published literature regarding the potential dose reduction related to image quality using Sinogram-Affirmed Iterative Reconstruction (SAFIRE) compared to Filtered Back Projection (FBP).

Background: Computed Tomography (CT) is one of the most used radiographic modalities in clinical practice providing high spatial and contrast resolution. However it also delivers a relatively high radiation dose to the patient. Reconstructing raw-data using Iterative Reconstruction (IR) algorithms has the potential to iteratively reduce image noise while maintaining or improving image quality of low dose standard FBP reconstructions. Nevertheless, long reconstruction times made IR unpractical for clinical use until recently.

Siemens Medical developed a new IR algorithm called SAFIRE, which uses up to 5 different strength levels, and poses an alternative to the conventional IR with a significant reconstruction time reduction.

Methods: MEDLINE, ScienceDirect and CINAHL databases were used for gathering literature. Eleven articles were included in this review (from 2012 to July 2014).

Discussion: This narrative review summarizes the results of eleven articles (using studies on both patients and phantoms) and describes SAFIRE strengths for noise reduction in low dose acquisitions while providing acceptable image quality.

Conclusion: Even though the results differ slightly, the literature gathered for this review suggests that the dose in current CT protocols can be reduced at least 50% while maintaining or improving image quality. There is however a lack of literature concerning paediatric population (with increased radiation sensitivity). Further studies should also assess the impact of SAFIRE on diagnostic accuracy.

INTRODUCTION

CT is one of the most used radiographic modalities in clinical practice but it also comes with a significant radiation dose to patients. Consequently, this research focused on dose reduction, particularly for paediatric examinations. These patients are more susceptible to long-term effects of radiation exposure, with higher potential for an increased lifetime risk of malignancy. Filtered back projection (FBP) is the standard reconstruction algorithm.

However IT developments in recent years permit iterative image reconstruction (IR) to become compatible with routine clinical practice.

Sinogram-Affirmed Iterative Reconstruction (SAFIRE) is an advanced iterative reconstruction technique recently developed by Siemens that requires less computing power and uses both FBP and raw data-based iterations. SAFIRE estimates the noise caused by fluctuations in neighbouring voxels in the raw-data. It subtracts the noise stepwise

in several validation loops. After the first correction loop, the result is compared with the original raw-data and an updated image is generated for the next iteration leading to further noise reduction. Where IR only uses a single correction loop, SAFIRE uses up to 5 correction loops to further decrease image noise[1]. The level of noise reduction and noise texture varies with SAFIRE strength for each reconstruction. SAFIRE strength does not translate the number of iterations and does not affect reconstruction time[2].

The purpose of this review article is to summarize the current research comparing SAFIRE and FBP. It investigates image quality and the potential of dose reduction provided by SAFIRE, compared to FBP. Data from articles are discussed bearing in mind SAFIRE's potential for dose reduction while maintaining diagnostic image quality.

DATA SOURCES AND SEARCHES

MEDLINE, ScienceDirect and CINAHL data bases were searched, using the following key words: comparison, filtered back projection, sinogram-affirmed iterative reconstruction, dose reduction, paediatric CT, computed tomography, image quality. The research equation was: (Computed tomography AND sinogram-affirmed iterative reconstruction AND radiation dose AND image quality AND filtered back projection) NOT (contrast media). We excluded articles concerning previous generation iterative reconstruction algorithms and articles focusing on cardiac CT on obese patients because of the difference of size between head examination and those patients.

Eleven articles were included in our review article, dating from 2012 to 2014, for examinations of chest, abdomen, head and cardiac on anthropomorphic phantoms and adult or paediatric patients.

MATERIALS AND METHODS

Patients/phantoms

Data came from CT scans performed on patients and phantoms. Patients were mainly adults but some studies focused on paediatric protocols. Scans were performed on physical and anthropomorphic phantoms (chest, head). One study used data from both patients and phantom scans for comparison.

Paediatric vs adult protocols

Three articles focused on paediatric examinations, "paediatric" denomination including children from 0 to 18 years old. Two explored cardiac CT and one abdomen. What mainly differs from adult studies were tube voltage (70 to 100-120 kVp) and tube current (lower mAs). Both were generally adapted to weight, size and age.

Data acquisition

Since all of the data-sets acquired in these studies had to be reconstructed with the SAFIRE algorithm, almost all exams were performed on the dual-source CT scanner Somatom Definition Flash from Siemens. Filtered back projections were sometimes acquired on other Siemens equipments.

The range of tube voltage explored was usually 100kVp and 120 kVp, sometimes also 80 kVp for ultra low doses. Tube current was variable, either fixed (at 25, 50 and 100 mAs or percentage reduction) or automatically modulated.

Images reconstruction

Acquisitions were reconstructed with FBP and SAFIRE. For SAFIRE, either all strengths (S1-S5) were explored or median strength like strengths S2 to S4 or S3 (recommended by manufacturer)[3].

Usually images were reconstructed with a medium smooth kernel or smooth and sharp kernels to compare changes in image quality.

Image quality analysis

For the physics analysis of image quality, noise and Signal-to-Noise Ratio (SNR) were the main criteria calculated. Contrast and Contrast-to-Noise Ratio (CNR) were less often measured. Only one study on phantoms went further by examining the Noise Power Spectrum (NPS), the spatial resolution, the linearity and accuracy of CT numbers.

For visual analysis, in most of the articles, the images were analysed by at least two radiologists with 3 years experience or more in a specific radiological field. Further details about the method of image analysis were often not provided. Visual criteria generally considered image noise (e.g., graininess), quality of contour delineation (i.e., sharpness) and general impression (i.e., overall image quality). Han et al. (2012)[4] referred to European Image Quality Assessment (i.e., sharpness, noise, noise texture, diagnostic confidence).

For visual analysis, a 4 or 5 point Likert scale is commonly used to evaluate image quality. Furthermore Wang et al. (2012) used a more precise 4 point scale on anatomic

details needed (e.g., level 1: lack of vessel wall definition due to marked motion artefact, poor vessel opacification, prominent structural discontinuity, or high image noise rendering the segment non-diagnostic).

R E S U L T S

Chest/thorax

Christe et al. (2013)[6] conclude that while using SAFIRE instead of FBP it was possible to achieve a dose reduction of 30, 52 and 80% for bone, soft tissue and air, respectively. Image quality was verified objectively using signal, noise and contrast measurements. With the same radiation dose, an average of 34% more CNR was achieved by changing respectively from FBP to SAFIRE. For the same CNR, an average of 59% dose reduction was produced for SAFIRE. The visual classification was given by two radiologists. For the same visual image quality, the dose could be reduced by 25% using SAFIRE. This study only used SAFIRE S3.

Wang et al. (2013)[7] explored SAFIRE strengths S2-S4 after excluding the extremes (S1 and S5), as they were considered to be, respectively, too "noisy" and too "smooth". The results of this study suggests there was no significant difference in the objective noise and SNR on mediastinal images between full-dose (FD) images reconstructed with FBP and half-dose images reconstructed with SAFIRE. But, on lung images, noise was significantly lower and SNR was significantly higher in half-dose images reconstructed with SAFIRE. Subjective image noise was similar on mediastinal and lung images with half-dose SAFIRE and full-dose FBP reconstruction.

Amongst all strengths, SAFIRE S3 had the best results for physics and visual image quality. Authors conclude that, compared to full-dose CT images reconstructed with the conventional FBP algorithm, SAFIRE with three iterations could provide similar or better image quality at 50% less dose.

Ghetti et al. (2013)[10] explored image quality using 3 phantoms. Noise was analysed on images reconstructed with all 5 SAFIRE strengths and a conventional medium-smooth kernel. Additionally, on images with strength SAFIRE S3, different kernels were selected to evaluate a possible difference in noise reduction due to the filter applied. For the same dose, noise reduction of iterative reconstruction increases with the SAFIRE strength applied in a proportional way.

CT number accuracy and linearity were verified to assess SAFIRE reconstructions influences on them. The different SAFIRE strengths did not change mean CT values and showed no considerable differences from values obtained with FBP.

Images were reconstructed with three different levels of SAFIRE strength (S1, S3, S5) and FBP at 3 different dose levels. CNR was measured for all images. CNR is always greater for SAFIRE and it increases with the strength of SAFIRE applied. But there is no evidence of a significant difference between the different filters in the SAFIRE outcomes. The spatial resolution was measured through different modules with two dose levels (at 120 kVp). Image texture changes increased with SAFIRE strength, resulting in an overall image quality improvement. Detail edge is sharper with less background noise using SAFIRE.

Abdomen

Greffier et al. (2013)[8] analysed the data from 10 patients who had a normal dose abdominal CT and who then underwent a second CT scan examination. The first sequence was acquired with 30% less mAs than the original CT and the second acquisition with 70% less mAs. The raw-data of the two scans was reconstructed with FBP and SAFIRE (S1-S5) and medium kernel.

Physics analysis concluded there was no significant difference in the measured signal when using FBP and SAFIRE. Noise significantly decreased (11% between FBP and SAFIRE 1) with SNR and CNR increase after each iteration. Good image quality was obtained with 30% less dose by using SAFIRE S2. Furthermore by using S5, it was possible to achieve up to 70% dose reduction while still maintaining image quality.

In the work of Kim et al. (2014)[9], a first group of paediatric abdominal patients was scanned with kVp and mAs modulation. Raw-data was reconstructed using SAFIRE (S2-S4). A second group of patients underwent the same exam in emergency room on a CT scanner with only mAs modulation and the raw-data was reconstructed with FBP. Physics and visual analysis of image quality showed that SAFIRE was able to achieve an average 64.2% in dose reduction compared to the control group with FBP. The objective image noise of the SAFIRE S2 and S3 was comparable to that of the control group. For visual image quality analysis, SAFIRE S2 and S3 showed better image quality than the control group in terms of diagnostic acceptability. Moreover, strength S3 scored better in terms of subjective image quality compared to S2.

Head

Schulz et al. (2013)[1] worked on data from a phantom head CT scan at different tube voltages and currents. Each

image was reconstructed using two different kernels with FBP and SAFIRE (S1-S5) algorithms. Image noise was evaluated and showed that compared to FBP, all iterative reconstruction techniques reduced the noise by 15%-85% depending on the iterative strength, rendering kernel, and dose parameters. Visual image quality was evaluated on images acquired at tube currents of 100% (FBP), 50% (SAFIRE), and 25% (SAFIRE). Visual evaluation of the images suggested that FBP images at full dose were preferred to 50% dose SAFIRE reconstruction. Their conclusion was that SAFIRE has a potential in CTs exam since even slight increase in iteration can yield important noise reduction.

Corcuera-Solano et al. (2014)[11] aimed to assess dose reduction for patients in the neurosurgical intensive care unit who undergo multiple head CT scans. While maintaining similar image quality and SNR levels, ultra-low-dose CT (ULDCT) reconstructed with SAFIRE represented a 68% lower CTDIvol compared to standard-dose CT (SDCT) with FBP technique in the same patients. SAFIRE reconstruction low-dose CT (LDCT) offered higher image quality than FBP standard-dose CT with no differences in SNR at a 24% lower CTDIvol. Compared with LDCT, ULDCT had significantly lower SNR but demonstrated clinically satisfactory measures of image quality. In visual analyses, there were no major differences in quality between ULDCT and SDCT.

Korn et al. (2013)[12] described an increase of 47% in CNR when using SAFIRE reconstruction instead of FBP in reduced-dose examination, because the degradation of image quality at lower dose was more than compensated by SAFIRE. Through objective measurements of image sharpness, they found that it was similar for FBP and SAFIRE reconstructions. Compared with FBP standard-dose (320 mAs) reconstructions, low-dose (255 mAs) SAFIRE reconstructions also allowed for an improvement in visual grading of noise as well as overall image quality.

Authors concluded that with 20% dose reduction, reconstruction of head CT by SAFIRE provides above standard objective and subjective image quality.

Cardiac

Han et al. (2012)[4] evaluated the impact of SAFIRE on image quality in paediatric cardiac CT datasets. From a visual point of view, no change was observed in spatial resolution, sharpness improved in 9% of cases, image noise in 63% cases and noise texture in 85% cases when using SAFIRE. The diagnostic confidence was similar in both groups. The improvement and reduction of noise was similar for helical and axial acquisition techniques. Visual image quality analysis resulted on a lower contrast from 1% for SAFIRE but clinically not significant, noise decreased (34%) and CNR (41%) and SNR (56%) increased with SAFIRE.

Wang et al. (2013)[5] analysed images from patients and phantoms. Data from dual source equipment was reconstructed using FBP and data from single source was reconstructed with SAFIRE and FBP, to assess image quality with only half dose. Images from the phantom suggested that noise proportionally decreased as current increased. No significant difference in SNR and noise was found between full-dose FBP and half-dose SAFIRE neither for phantom nor patients. Similar visual results between full-dose FBP and half-dose SAFIRE were performed in visualising coronary segments. For half-dose FBP, significantly fewer segments were visible. It suggested that with an estimated dose reduction of 50%, there was no significant difference in noise, SNR and overall image quality with SAFIRE reconstruction compared to full-dose standard protocol reconstructed with FBP.

Nie et al. (2014)[3] evaluated the impact of SAFIRE on image quality for a tube voltage of 70 kVp. The mean scores of visual analysis were significantly higher with SAFIRE algorithm than with FBP algorithm regarding to graininess, sharpness and overall image quality. Noise was lower and SNR and CNR significantly higher with SAFIRE. Radiologists evaluated the diagnostic accuracy. SAFIRE scored better than FBP algorithm but no significant difference in diagnostic accuracy between FBP and SAFIRE was found ($p > 0.05$).

The authors concluded that, for a same tube current, physical and visual image quality were significantly improved with SAFIRE.

Table 1: Results in dose reduction and image quality (IQ) evaluation

Authors	Part of body examined	SAFIRE Strength	Dose reduction	Image quality results
Christe et al. (2013)[6]	Chest	S3	80% at same noise 45% at same SNR 59% at same CNR 25% at same subjective IQ	-44 % noise, +36 % SNR, +34 % CNR with SAFIRE Better subjective IQ for SAFIRE with same dose
Wang et al. (2013)[7]	Chest (low dose)	S3	similar IQ with FBP 100% dose and SAFIRE 50% dose	Full-dose FBP noise comparable to half-dose SAFIRE Subjective IQ evaluation in noise, SNR and lesion detection comparable with full-dose FBP or half-dose SAFIRE
Ghetti et al. (2013)[10]	Chest, Water, Catphan 600 and 3D phantom	S1-S5 S1,S3,S5	Unique dose of 13.4 mGy tested for noise Doses tested for CNR : 20.2, 13.4 and 6.7 mGy	Up to 60% noise reduction with SAFIRE 5 for 2mm slices with same dose Noise decreases and CNR increases when SAFIRE strength rises
Greffier et al. (2013)[8]	Abdomen	S1-S5	Dose reduced at 30% and 70% from full dose	SNR and CNR improved with the increase in SAFIRE levels
Kim et al.(2014)[9]	Abdomen (paediatric)	S2,S3,S4	64.2% average dose reduction for similar image quality with SAFIRE	Noise decreases and IQ increases with SAFIRE strengths No significant difference between SAFIRE S4 and FBP
Schulz et al. (2013)[1]	Head: paranasal sinuses	S1-S5	100% FBP, 50% SAFIRE, 25% SAFIRE	Image noise always greater with FBP With 25% dose, mean noise reduction 47.5% for 3mm and 49.4% for 1mm slices with SAFIRE Best IQ with 100% dose level with FBP
Corcuera-Solano et al. (2014)[11]	Head	S3	ULDCT 68% dose reduction LDCT 24% dose reduction	Image quality similar with full dose FBP and LDCT reconstructed with SAFIRE S3
Korn et al. (2013)[12]	Head	S3	20% dose reduction	+ 48% SNR, + 47% CNR with SAFIRE for same dose Similar sharpness IQ SAFIRE scored better than FBP
Han et al. (2012)[4]	Cardiac	-	-	- 34% noise, + 56% SNR, + 41% CNR using SAFIRE vs FBP using the same dose
Wang et al. (2013)[5]	Cardiac Water phantom	-	Simulating a 50% radiation dose reduction	No significant noise and SNR difference and equivalent image quality between full dose FBP and half dose SAFIRE
Nie et al. (2014)[3]	Cardiac	S3	Same dose 70 kVp	Significantly lower image noise Significantly higher SNR and CNR for SAFIRE Higher scores for subjective IQ with same dose

DISCUSSION

Although specific values differ from one study to another, all studies concluded that SAFIRE allows for a significant dose reduction, while maintaining adequate image quality. Nevertheless some limitations were identified.

The studies included in this review used different parameters to measure image quality. There was no standard way in how both physical and visual image quality was measured. Different sizes of ROI's and different Likert scales were used. Furthermore, not all articles assessed both physical and visual image qualities.

The studies assessing visual image quality only used two radiologists as observers. In order to reduce observer bias, a larger group is needed. Monitor characteristics and display parameters were completely missing as well as the visual acuity performance of the observers.

The images were only classified according to their diagnostic or visual quality, but not their diagnostic accuracy. More studies must be done regarding if SAFIRE provides better diagnostic accuracy than FBP.

In some studies the image sets were acquired using different equipment for FBP and SAFIRE reconstructions.

That implicates possible changes in acquisition protocol and might not allow a proper comparison.

Studies did not always consider all SAFIRE strengths with no clear explanations about exclusion criteria. It doesn't give a complete answer on the potential dose reduction and image quality with SAFIRE.

CONCLUSION

All articles reported an important noise reduction when using SAFIRE reconstruction instead of FBP at equal dose levels. Noise level decreased proportionally when increasing SAFIRE strength. Some articles suggested that a similar visual and physical image quality between FBP and SAFIRE can be achieved when reducing dose to 50%. No significant difference was measured in CNR between both reconstruction methods. This could suggest the usefulness of SAFIRE in patient radiation protection. Consequently, its use will likely become widespread, allowing exams to be performed using a lower radiation dose, particularly in paediatric examination.

The manufacturer recommended the use of SAFIRE S3 for an optimal image quality and this was confirmed by several articles in general appreciation of the image.

Although from a physics point of view, significant dose reductions are feasible, it is essential to verify the diagnostic accuracy of the image with observer analysis. Studies should also be done regarding other fundamental factors for dose reduction, e.g. detector efficiency and dose modulation (kVp and mAs) and their potentials combined with SAFIRE's ones.

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