Iterative Reconstruction in CT

Review Article – An evaluation of SAFIRE's potential to reduce the dose received by paediatric patients undergoing CT: a narrative review

Synnøve Borge[a], Nina Campbell[b], Ana Gomes[c], Aysha M. Raszkowski[a], Jan Willem Rook[d], Audun Sanderud[a], Anique Vallinga[d], Audrey Vouillamoz[e], Carst Buissink[d]

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

KEYWORDS

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ABSTRACT

Introduction: The purpose of this review is to gather and analyse current research publications to evaluate Sinogram-Affirmed Iterative Reconstruction (SAFIRE). The aim of this review is to investigate whether this algorithm is capable of reducing the dose delivered during CT imaging while maintaining image quality. Recent research shows that children have a greater risk per unit dose due to increased radiosensitivity and longer life expectancies, which means it is particularly important to reduce the radiation dose received by children.

Discussion: Recent publications suggest that SAFIRE is capable of reducing image noise in CT images, thereby enabling the potential to reduce dose. Some publications suggest a decrease in dose, by up to 64% compared to filtered back projection, can be accomplished without a change in image quality. However, literature suggests that using a higher SAFIRE strength may alter the image texture, creating an overly 'smoothed' image that lacks contrast. Some literature reports SAFIRE gives decreased low contrast detectability as well as spatial resolution. Publications tend to agree that SAFIRE strength three is optimal for an acceptable level of visual image quality, but more research is required. The importance of creating a balance between dose reduction and image quality is stressed. In this literature review most of the publications were completed using adults or phantoms, and a distinct lack of literature for paediatric patients is noted.

Conclusion: It is necessary to find an optimal way to balance dose reduction and image quality. More research relating to SAFIRE and paediatric patients is required to fully investigate dose reduction potential in this population, for a range of different SAFIRE strengths.

INTRODUCTION

Computed tomography (CT) is valuable for diagnostic insight. However, X-ray images taken during CT examinations expose the patient to a high dose of radiation, which has the potential to cause cancer.

Recent US cancer risk projections estimate 1 cancer per 1000 brain CT scans for patients under 5 years of age[1]; it is therefore understandable that radiation dose has been a longstanding concern for paediatric patients, particularly when multiple scans are required.

One of the possible solutions for dose reduction is the use of iterative reconstruction instead of conventional filtered back projection (FBP). Sinogram Affirmed Iterative

Reconstruction (SAFIRE), developed by Siemens, is one of the newest available iterative algorithms. Based on its noise reduction capabilities, it is believed that this algorithm may have the potential to significantly reduce dose in children undergoing CT scans without sacrificing image quality.

This review attempts discusses whether SAFIRE is suitable for dose reduction in patients undergoing CT. Our focus is to analyse whether dose can be reduced for paediatric patients whilst maintaining an image quality that is acceptable for diagnosis.

Literature search and review strategy

Literature searching was conducted on several computerised databases (ScienceDirect, PubMed), online journals and publishers were also utilised, such as AJR Online and Springer.

As SAFIRE is relatively new, published articles available are limited. English articles from all years of publishing were included in this literature review; dates ranged from 2012 to 2014. Keywords used whilst searching for literary references were: SAFIRE, paediatric, CT. Due to a small number of articles, research focussing on SAFIRE being used for adults was also considered for this review article.

Articles were excluded on the basis of not being related to: SAFIRE CT reconstruction, CT exposure for paediatric patients and the related risks, comparisons of SAFIRE with standard FBP. Most articles related to angiography were also excluded due to the use of high-contrast dyes. Ultimately, 21 articles were selected for inclusion in this review article.

DISCUSSION

CT for paediatric patients

Use of CT has increased in recent years and, according to studies by Shah and Brenner et al.[2-3], in 2007 there were 62 million CT examinations taken in the USA; 7 million of which were children. This is a concern for paediatric patients and, unfortunately, this number is steadily increasing each year.

The risk per unit dose for paediatric patients is greater than for adults, and it is a concern that some institutions do not lower the exposure for younger patients[4].

There are two reasons why children have a higher risk of developing cancer due to radiation exposure. Firstly, the life expectancy is longer than in adults. Secondly, children have rapidly dividing cells which makes them more sensitive to radiation[2].

The radiosensitivity of children has been subject to debate and it is currently estimated that for 25% of cancer types, children are more susceptible than adults, and for 20% of tumour types the data is inconclusive[5]. It has been estimated that a one year old child is as much as ten times more susceptible to radiation-induced cancer than an adult[4].

In recent years, based on the steadily increasing use of CT, more attention has been focussed on trying to reduce patient dose. Frush and McCollough et al.[6-7] describe different strategies that are currently used or have been proposed to solve this problem, such as the use of different modalities or a reduction in acquisition parameters. Another possibility is the use of an iterative reconstruction (IR) algorithm instead of FBP.

FBP and IR

CT image reconstruction was a longstanding issue of debate, mostly because the images created with the original technique (back projection) did not have sufficient quality. Back projection created projections of the object from many angles and the end result was a blurry image. FBP was a development of back projection, which additionally filtered all of the raw data to minimize artefacts and give better overall image quality[8]. FBP is currently the most used reconstruction technique. Unfortunately, this algorithm has a trade-off between dose and image quality, which limits by how much the dose can be reduced[9].

IR techniques generate images using several iterative steps to create images that are more precise[10], meaning dose can be lowered. IR was used in first generation CTs, but despite it's potential for dose reduction, it was dismissed due to too much data and too little computer power available[11].

In the past few years new and improved IR algorithms have emerged. Unfortunately there are concerns among some radiologists that IR creates a 'smeared' effect[12], which in turn could mean that pathology could go unnoticed. Equally there is a perception that there is not yet an IR technique which produces better visual (clinical) image quality than FBP for a lower dose[13]. However it is well known that physical measures of image quality (e.g., noise and CNR) improve when using IR.

One of the first generation IR algorithms to be introduced into daily practice was IRIS (Iterative Reconstruction in Image Space, 2009). A study by Hu et al. noted that IRIS gave the possibility of 40% dose reduction while maintaining image quality. Unfortunately, the time needed to reconstruct the images was 4-5 times longer than for FBP[14], making IRIS difficult to use clinically.

SAFIRE

The Sinogram-Affirmed Iterative Reconstruction algorithm is a new technique developed by Siemens, and it has been widely considered innovative in comparison to its predecessors[15]. SAFIRE uses both projection space data and image space data to reconstruct images quickly with high spatial resolution. There are currently five different strengths of SAFIRE that can be utilised, with SAFIRE 5 being the highest[16].

One of the earliest publications (Schulz et al.[17]) relating to SAFIRE tested all five of the strengths, for soft and hard kernels, for CT slices of 1 mm and 3 mm. It was suggested that SAFIRE performed best in the bony kernel and that SAFIRE 5 had the greatest noise reduction potential, with noise being reduced by 15-85%. A similar result was found in the publication of Wang et al.[9], who also found that noise was reduced in SAFIRE images. Furthermore, they compared full-dose FBP images with half-dose SAFIRE 3 images and concluded the noise to be of the same level, suggesting that SAFIRE had a great potential for dose reduction whilst maintaining image quality.

This potential was furthered by a study conducted by Kalmar et al. who investigated the use of SAFIRE for thoracic and abdominal CTs for standard dose FBP and reduced dose IR[18]. Subjectively, both images received approximately the same image quality ratings. It was evaluated that an average dose reduction of 64% and 58% was achieved for thoracic and abdominal CTs respectively. Similarly, Baker et al.[19] found that SAFIRE created images with less noise at 70% and 50% dose when compared to FBP at 100%. It was concluded that SAFIRE could create images with higher CNR at lower doses. However, for low-dose and low-contrast images, objects were invisible. Thus, Baker et al. emphasised a need for finding a balance between dose and image quality.

On the other hand, a study by Bratanova et al. concluded that low contrast detectability was higher with SAFIRE than FBP, and it increased with SAFIRE strength. They used two phantoms (low and high contrast), where one part simulated lesion-free background and with another part simulating hypodense lesions. The results showed that not only did SAFIRE produce images with lower noise, but also equal spatial resolution compared to FBP[20].

The diagnostic accuracy of SAFIRE was also studied by Moscariello et al. This study used full dose FBP and half dose SAFIRE images. Half dose images were created using 50% of the raw data containing the full dose projections. The results stated that SAFIRE had higher CNR and lower noise. At the same time, image quality was equal or better than that of FBP. This allows for a possible dose reduction of 50% (FBP: 6.4 ± 4.3 mSv and SAFIRE: 3.2 ± 2.1 mSv)[21].

A phantom-based study by Ghetti et al.[15] suggested that the quality-dose balance recommended by Baker[19] could be achieved by utilising the different strengths of SAFIRE. A noise-power-spectrum (NPS) showed that SAFIRE 4 and SAFIRE 5 performed better at lower frequencies, and concluded that this could be the compromise for dose and image quality in SAFIRE. Furthermore, a study conducted by Yang et al.[22] tested all strengths of SAFIRE for low dose lung CT images and determined that a higher strength did not necessarily mean a greater image quality, even though the noise decreased. This was because the higher strengths altered the texture pattern of the image and resulted in unfamiliar image impressions, such as blotchy artefacts in sharp transition zones due to excessive smoothing. Yang et al. concluded that SAFIRE 3 was optimal for the lung. Similarly, a second study[23] investigated SAFIRE 3 and SAFIRE 4 for lung CTs for patients with mean BMI of 22.7 and 25.8 kg/m^2 respectively, and found that all 120 datasets were feasible for analysis. Diagnostic image quality was assessed as 100% and 98% for SAFIRE at 100 kVp and 80 kVp, an improvement from the 96% and 88% assessed for FBP. Subsequently, doses of 0.7 mSv and 0.4 mSv were deemed acceptable for diagnostic imaging with the use of SAFIRE, further suggesting that individually selecting the strength level for IR is advantageous.

Following this, another experiment performed by Lee et al. tested to see if an ultra low dose CT (ULDCT) of 0.3 mSv reconstructed using SAFIRE was achievable. This was compared with a reduced dose CT (RDCT) of 2.9 mSv. It was found that 91.9% of ULDCT and 100% of RDCT were considered sufficient for diagnosis[24]. However, patients with a BMI of less than 25 had a greater success rate of 95% for SAFIRE, thus agreeing with the previous study. From the results of the previous study, completed on adults, it could be implied that SAFIRE's ability is greatly affected by selecting the relevant strength depending on patient size or BMI. This could concern paediatric patients due to their smaller sizes and smaller BMI. However, studies assessing SAFIRE's use with children for a range of BMIs or sizes are limited.

Han et al. studied the use of SAFIRE for cardiac CT datasets, for patients with a mean age of 4.1 years[25]. They adjusted the kVp according to the weight of the patient: 80

kVp if under 65 kg, 100 kVp if above. Their results were in agreement with previous studies; there was little to no difference in diagnostic quality of FBP versus SAFIRE images, and IR images had a decrease in noise and an increase of SNR and CNR. Effective dose and SAFIRE strength used was not reported.

The strength of SAFIRE frequently goes unmentioned in articles, and so it is challenging to predict which strength might be the most efficient for younger patients. Based on aforementioned studies it might be concluded that SAFIRE 2 or SAFIRE 3 would be best, depending on patient size. Kim et al.[26] investigated SAFIRE strengths 2, 3 and 4 specifically, for paediatric abdominal CT patients with a range of kVp and mAs. SAFIRE 3 was concluded as optimal for subjective image quality but SAFIRE 4 was optimal for objective image quality, thus agreeing with previously mentioned studies relating to the lung. It is suggested that the mid-strengths (2, 3 or 4) tend to rate higher for physical and visual image quality measures, due to SAFIRE 5 becoming too blurred. According to the study the possibility of 64.2% dose reduction exists for paediatric abdominal patients.

CONCLUSION

It can be concluded that SAFIRE can significantly reduce noise in images in comparison to FBP. Multiple articles have stated the potential of SAFIRE for significant dose reduction, with most implying a capability of reducing dose by around 50%.

Overall, SAFIRE does have the potential to significantly reduce dose delivered to paediatric patients undergoing CT. However, more research is required to study the extent at which the dose can be reduced, as articles relating to paediatric patients are limited. It is also imperative to further test different strengths of SAFIRE, particularly at lower levels of kVp and mAs, for paediatric patients in order to test the effects on image quality and dose reduction.

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