An investigation of spatial resolution and noise in reconstructed CT images using iterative reconstruction (IR) and filtered back-projection (FBP)

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Abstract. This study compared the spatial resolution and the amount of noise in CT images reconstructed using the iterative reconstruction (IR) and filtered back-projection (FBP) techniques. We used a circular homogeneous phantom (pixel value of 0.5) containing a small circle at its center, with a diameter of 0.53-cm and a pixel value of 1.0. In order to reconstruct the image, we used the simultaneous iterative reconstruction technique (SIRT) with 5, 15, 25, 35 and 45 iterations respectively, and FBP with a Ram-Lak filter. The spatial resolution of the reconstructed image was characterized by the modulation transfer function (MTF) and image noise was characterized by the standard deviation within the homogeneous area. We found that the spatial resolution using SIRT with 35 iterations is similar to using FBP. The spatial resolution using SIRT tends to be worse using less than 35 iterations, and it tends to be better using more than 35 iterations. Using SIRT, image noise decreased with increasing iterations. The standard deviation for the SIRT technique using 45 iterations was about 0.02 similar to the FBP technique. Thus, SIRT could potentially produce better spatial resolution than the FBP technique with comparable image noise.

1. Introduction

In tomography, there are two main techniques used to reconstruct the images, namely filtered back-projection (FBP) and iterative reconstruction (IR) [1]. Iterative reconstruction (IR) was used in the early CT scans. However, the main drawback of the IR technique was that it needs very long computation times [2]. This led to it being replaced by the FBP technique in clinical CT applications. The FBP technique produces high quality images with a fast computation time, and it is considered the standard technique for CT image reconstruction. There are many filters that can be used in FBP, including the Ram-Lak, Shepp-Logan, Butterworth, cosine, Hamming and Hann filters [3]. In clinical settings, the filters are given straightforward names, such as "bone filter", "soft tissue filter" and so on.

Nowadays, there is considerable concern about CT dose [4-6]. Compared to other radiological modalities, CT delivers considerably more dose to the patient [7]. Consequently, efforts have been made to reduce the dose in a CT examination. One way is by using modified IR [8]. However, the

modified IR technique is considered proprietary, with very little information on the details and algorithmic principles [2]. There are at least two methods of modified IR: statistical iterative reconstruction [9] and model-based iterative reconstruction [10].

The algorithms of standard IR that have been widely known are the algebraic reconstruction technique (ART) [11], simultaneous ART (SART) [12], and simultaneous iterative reconstruction technique (SIRT) [13]. In this study, we compare the efficacy of SIRT with standard FBP by analyzing the resulting spatial resolution and image noise.

2. Method

2.1. Overview
The steps in this study are shown in Figure 1. The first step is to design a point source phantom. The second step is to perform projections with a parallel beam, using angular increments of 1°. The third step is to reconstruct the image using both FBP and SIRT with iterations of 5, 15, 25, 35 and 45. The spatial resolution of the resulting images were then analyzed using modulation transfer function (MTF) curves, and the noise in the images was computed using the standard deviations within homogeneous areas. All the steps were implemented using MatLab software.
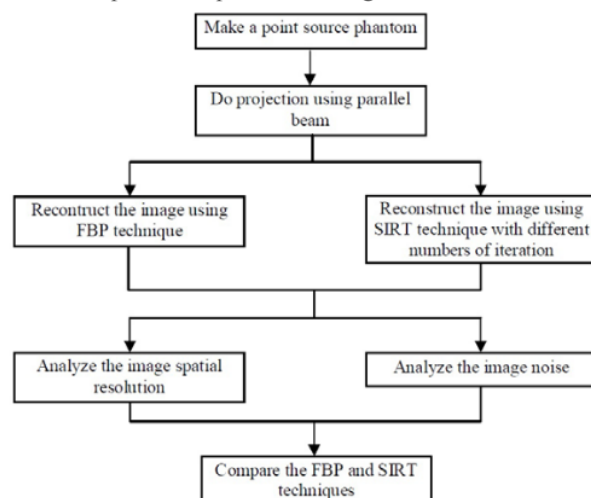

Figure 1. Flow chart diagram of this study

2.2. Design of Phantom
A point source phantom was used for the comparison of spatial resolution and noise image. The phantom consists of three circles with different diameters and different pixel values. The diameter of largest circle was 32.00 cm, the diameter of the second circle was 31.07 cm, and the diameter of the smallest circle was 0.53 cm. Pixel values in the smallest circle was 1.0, the pixel values outside the smallest circle and inside the second circle was 0.5, and the pixel values outside the second circle and inside the largest circle was 1.0. The total number of pixels was 512 x 512, representing a field of view of 32 cm.

2.3. The FBP Technique
Currently the standard algorithm for image reconstruction is filtered back projection (FBP). Back-projection can be expressed as the sum of the x-rays passing through a point (x, y) at any angle θ. Back projection aims to fill the voxels of an image with the values of the projection data. The main

drawback of this technique is that the resulting image will appear blurry due to star-like artifacts. This blur can be eliminated by performing mathematical filtering of the projection data (i.e., the sinograms), before doing back-projection. The mathematical filter used in this study is the cropped ramp filter or Ram-Lak filter.

2.4. The SIRT Technique

Another technique for image reconstruction with a low blur is the iterative reconstruction (IR) technique. The first CT scanners used this reconstruction, but because it was computationally very slow it was later abandoned. Actually, the IR technique can produce a relatively good image, even with a low current-time product (mAs). As a result, the CT radiation dose can be reduced significantly. More recently, the IR technique has been modified using statistical methods (statistical iterative reconstruction) and using model-based methods (model-based iterative reconstruction). There are several standard algorithms in the IR. In this study, we used simultaneous iterative reconstruction technique (SIRT). In the SIRT, image enhancement is performed iteratively after a complete projection for all angles.

2.5. MTF and Noise Calculation

In this study, the spatial resolution image was analyzed using the PSF and MTF curves [14], and image noise calculated as the standard deviation in homogeneous areas. Region of interests (ROIs) for the calculation of MTF and noise are shown in Figure 2. The ROI for the calculation of PSF and MTF was at the center of the image (256, 256), with a pixel size of 128 x 128.

The flow chart for the PSF and MTF calculations is shown in Figure 3. The image reconstructions, from both the FBP and SIRT techniques are read, and the images cropped at their center to give a pixel size of 128 x 128. The pixels are then summed along the y- direction to obtain the profile (summation of pixels) for the x-direction. After that is the zeroing process, so that the values of PSF at both edges of the profile are zero. The resulting curve is known as the point spread function (PSF). The PSF is then normalized so that the total of all data is equal to one, and Fourier transformation used to transform the data to the frequency domain to give a plot of the modulation transfer function (MTF).
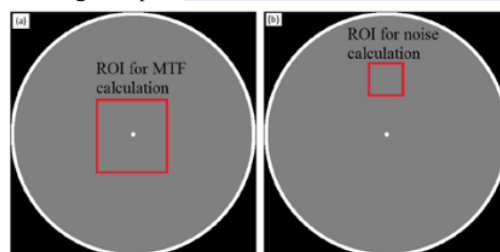
Figure 2. ROI for (a) PSF and MTF calculations and (b) ROI for noise calculation

Noise is calculated as the standard deviation of a homogeneous area. In this study, we used an area of 50 x 50 pixels, centered at position (256, 128). The reconstructed image was cropped to this region, and the standard deviation calculated.
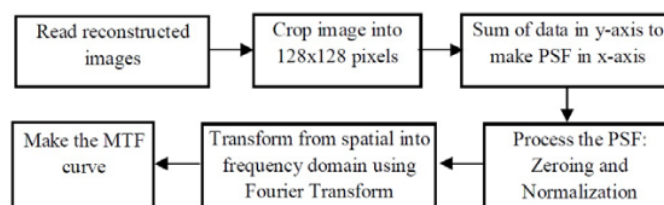
Figure 3. Flow chart of PSF and MTF calculations

3. Results

3.1. Reconstructed Images

Figure 4 is the result of the reconstruction of the object of a point source phantom using FBP and SIRT for various iterations. Figure 4a is a result of FBP reconstruction, and Figs. 4b-f are the results of SIRT for the iterations 5, 15, 25, 35 and 45 respectively. The FBP method produces a clear image, without any appreciable blur or noise. The reconstructed images using the SIRT technique are strongly dependent on the number of iterations. At the 5th iteration, blurring is still apparent, but it decreases with increasing iterations until at the 25th iteration, image quality using the SIRT technique is comparable to the FBP technique.

3.2. PSF and MTF Curve

PSF curves of the reconstructed image from FBP and SIRT for various numbers of iterations are shown in Figure 5 (left). The PSF peak value increases with increasing iterations. At the 35th iteration of the SIRT technique the PSF curve is similar to the FBP technique, and at iterations above 35 the peak of the PSF curve is much higher than with the FBP technique. However, at the tails, the PSF using SIRT do not directly equal zero, but are negative. To return to the zero position requires a shift of approximately 30 mm.

The corresponding MTF curves are shown in Figure 5 (right). The MTF curve shows clearly that the spatial resolution of the reconstructed image by SIRT increases with the number of iterations. At the 35th iteration, the MTF curves using SIRT and FBP are similar, while above 35, the spatial resolution from SIRT is higher than from FBP. The cut-off spatial frequency for all curves remains at approximately 2 cycles / mm.
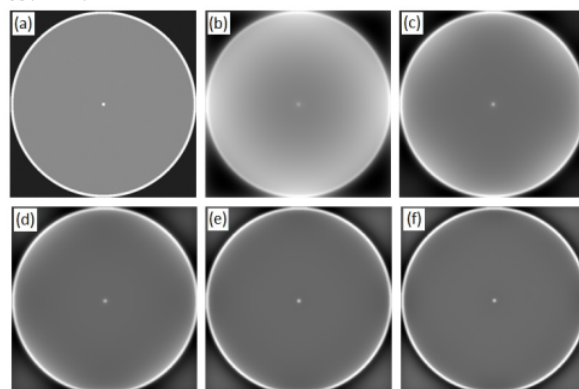

Figure 4. Reconstructed images of a point souce phantom using FBP and SIRT for various iterations.a. FBP, b. SIRT 5, c. SIRT 15, d. SIRT 25, e. SIRT 35, f. SIRT 45
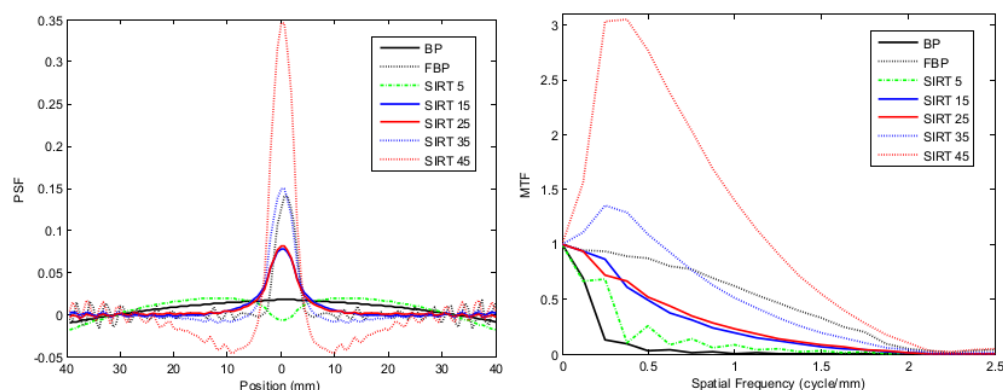
Figure 5. PSF curves (left) and MTF curves (right) of reconstructed images using FBP and SIRT for various numbers of iterations

3.3. Noise of Image

The average pixel values and standard deviations (noise) for a number of reconstructed images are shown by Table 1. The value of the original pixel in our point source phantom is 0.5. The FBP technique generates pixel values (0.49 ± 0.01) close to the original value of phantom. For the SIRT technique the values are also influenced by the number of iterations. The greater number of iterations, the closer the average pixel value is to 0.5, and the smaller is the standard deviation. For example, at iteration 45, the pixel value is 0.51, and the standard deviation (noise) is 0.02.

Table1. The average pixel value and its standard deviation for reconstructed images by FBP and SIRT for various iterations

Pixel Value	BP	FBP	SIRT 5	SIRT 15	SIRT 25	SIRT 35	SIRT 45
Average	386.23	0.49	1.51	-0.10	0.32	0.46	0.51
Standard deviation	5.10	0.01	0.69	0.06	0.04	0.03	0.02

4. Discussion

This study aims to compare the spatial resolution and noise of reconstructed images using the SIRT and FBP techniques. The results indicate that in the SIRT technique, the spatial resolution and noise are strongly influenced by the number of iterations. As the number of iterations increase, the spatial resolution increases and the noise decreases. Our results show that using the SIRT technique with 35 iterations, the spatial resolution is similar to that obtained with FBP. If the number of iterations is greater than 35, the SIRT produces a higher spatial resolution. The noise produced by the SIRT technique using 45 iterations is similar to the noise produced by FBP. If the number of iterations is greater than 45, SIRT produces less noise. Thus the SIRT method can potentially produce images with better spatial resolution and noise, if a relatively large number of iterations (>45) is used. Clinically, the number of iterations can be set as required.

However, although SIRT can produce higher spatial resolution and lower noise, the characteristics of the reconstructed images are very different from those reconstructed by FBP. This is evident from the very different shapes of the underlying PSF curves. For instance, the tail area of the PSF curves for FBP are always positive, but the PSF curves for the SIRT technique have negative values, and this area becomes larger with the increase in the number of iterations. This difference direct impacts the

shape of the MTF curves. It should be noted that the SIRT method produces artifactual values outside the phantom, which is cause for concern.

The major advantage of iterative reconstruction is that noise visible in the sinogram can be reduced, so that small mAs can be used, with a consequent reduction in radiation dose to the patient. In subsequent studies, we will add synthetic noise to the projection data to evaluate the effect of noise in images reconstructed using SIRT.

5. Conclusions
The spatial resolution and noise in the image reconstructed using the SIRT method is influenced by the number of iterations. Larger numbers of iterations result in greater spatial resolution and less noise. At the 35th iteration the spatial resolution is similar to using FBP reconstruction, and at the 45th iteration the noise is similar to using FBP.

Acknowledgements

References
[1] Koch W, Hamann C, Welsch J, Po¨pperl G, Radau P E, and Tatsch K 2005 Is iterative reconstruction an alternative to filtered backprojection in routine processing of dopamine transporter SPECT Studies? *J. Nucl. Med.* **46** 1804–1811

[2] Beister M, Kolditz D, Kalender W A 2012 Iterative reconstruction methods in X-ray CT *Phys. Medica.* **28** 94-108

[3] Jun-Yan R, Guo-Tao F, Cun-Feng W, Cui-Li S, and Long W 2010 Measurement of spatial resolution of the micro-CT system *Chinese Physics C.* **34** 412-416

[4] Brenner D J and Hall E J 2007 Computed tomography-An increasing source of radiation exposure *N. Engl. J. Med.* **357** 2277-2284

[5] Anam C, Haryanto F, Widita R, Arif I, Dougherty G, and McLean D 2017 The impact of patient table on size-specific dose estimate (SSDE) *Australas Phys. Eng. Sci. Med.* **40** 153–158

[6] Anam C, Haryanto F, Widita R, Arif I, and Dougherty G 2016 A fully automated calculation of size-specific dose estimates (SSDE) in thoracic and head CT examinations *J. Phys.: Conf. Ser.* **694** 012030.

[7] Bauhs J A, Vrieze T J, Primak A N, Bruesewitz M R, McCollough C H 2008 CT dosimetry: comparison of measurement techniques and devices *RadioGraphics.* **28** 245-253

[8] Kalender W A 2014 Dose in x-ray computed tomography *Phys. Med. Biol.* **59** R129-R150

[9] Hussain F A, Mail N, Shamy AM, Alghamdi S, and Saoudi A 2016 A qualitative and quantitative analysis of radiation dose and image quality of computed tomography images using adaptive statistical iterative reconstruction *J. Appl. Clin. Med. Phys.* **17** 419-432

[10] Pickhardt P J, Lubner M G, Kim D H, Tang J, Ruma J A, del Rio A M, and Chen G 2012 Abdominal CT with model-based iterative reconstruction (MBIR): Initial results of a prospective trial comparing ultralow-dose with standard-dose imaging *Am. J. Roentgenol.* **199** 1–9

[11] Gordon R, Bender R, and Herman G T 1970 Algebraic reconstruction techniques (ART) for three-dimensional electron microscopy and x-ray photography *J. Theor. Biol.* **29** 471-482

[12] Andersen A H and Kak A C 1984 Simultaneous algebraic reconstruction technique (SART): a superior implementation of the ART algorithm *Ultrason Imaging* **6** 81-94

[13] Gilbert P 1972 Iterative methods for the three-dimensional reconstruction of an object from projections *J. Theor. Biol.* **36** 105-117

[14] Kayugawa A, Ohkubo M, and Wada S 2013 Accurate determination of CT point-spread-function with high precision *J. Appl. Clin. Med. Phys.* **14** 216-226

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