A new approach for quantitative evaluation of reconstruction algorithms in SPECT

Article · January 2006

Hossein Rajabi
Tarbiat Modares University

S. Mahmoud Reza Aghamiri
Shahid Beheshti University

A new approach for quantitative evaluation of reconstruction algorithms in SPECT

E. Raeisi[1], H. Rajabi[1*], S.M.R. Aghamiri[2]

[1] Department. of Medical Physics, Tarbiat Modares University, Tehran, Iran
[2] Division of Radiation Medicine, Shahid Beheshti University, Tehran, Iran

Background: In nuclear medicine, phantoms are mainly used to evaluate the overall performance of the imaging systems, and practically there is no phantom exclusively designed for the evaluation of the software performance. In this study the Hoffman brain phantom was used for quantitative evaluation of reconstruction techniques. The phantom is modified to acquire tomographic and planar image of the same structure. The planar image may be used as the reference image to evaluate the quality of reconstructed slices, using the companion software developed in MATLAB. **Materials and Methods:** The designed phantom was composed of 4 independent 2D slices that could have been placed juxtapose to the 3D phantom. Each slice was composed of objects of different size and shape (for example: circle, triangle, and rectangle). Each 2D slice was imaged at distances ranging from 0 to 15 cm from the collimator surface. The phantom in 3D configuration was imaged acquiring 128 views of 128×128 matrix size. Reconstruction was performed using different filtering condition and the reconstructed images were compared to the corresponding planar images. The modulation transfer function, scatter fraction and attenuation map were calculated for each reconstructed image. **Results:** Since all the parameters of the acquisition were identical for the 2D and the 3D imaging, it was assumed that the difference in the quality of the images has exclusively been due to the reconstruction condition. The planar images were assumed to be the most perfect images which could be obtained with the system. The comparison of the reconstructed slices with the corresponding planar images yielded the optimum reconstruction condition. The results clearly showed that Wiener filter yields superior quality image among the entire tested filters. The extent of the improvement has been quantified in terms of universal image quality index. **Conclusion:** The phantom and the accompanying software were evaluated and found to be quite useful in determining the optimum filtering condition and mathematical evaluation of the scatter and attenuation in tomographic images. **Iran. J. Radiat. Res., 2006; 4 (2): 77-80**

Keywords: *SPECT, image quality, Hoffman phantom, γ image reconstruction.*

INTRODUCTION

Nuclear medicine phantoms are mainly designed for quality control purposes. They usually measure the overall performance of the imaging systems (1). The performance of the single photon emission computed tomography systems (SPECT) depends on both the hardware characteristics and the software efficiency. The phantoms available are mainly used for the hardware qualification rather than the software evaluation. Though the acquired images are sometimes used for the evaluation of processing procedures (e.g. filters), the results are quite relativistic (2). Phantom of Jaszezak is an exclusively designed quality control of the SPECT systems. The raw images of the phantom can be reconstructed using different methods, and the resultant images can be compared with each other; however, the images are not comparable with a reference image.

Huffman brain phantom is somehow a modification of Jaszezak phantom. The phantom comes in 2D and 3D models. The 2D model is composed of a single cross section that is filed with the activity (3). The 3D model is composed of several slices that are assembled to form an integrated 3D phantom. Huffman phantom is very important for evaluation of reconstruction method (4). Basically, the planar images are considered to be reference for the corresponding reconstructed slice images. However, the comparison is quite subjective and the resultant image can only be compared with the reference slice visually. Moreover, the pattern of the 2D slice phantom dose not reflects the inter-plane scatter that would be present in a 3D

***Corresponding author:**
Dr. Hossein Rajabi, Dept. of Medical Physics, School of Medical Sciences, Tarbiat Modares University, Tehran, Iran.
***Fax:** +98 21 88006544*
***E-mail:** hrajabi@modares.ac.ir*

configuration [5, 6].

In brief, quantitative evaluation of contrast, resolution and uniformity are not possible with Huffman phantom and the effects of scatter and attenuation are hard to consider.

In this paper we have proposed a modification to the Huffman and Jaszezak phantoms and a simple method which might be useful in the evaluation of reconstruction technique and quantitative evaluation of scatter and attenuation correction methods.

MATERIALS AND METHODS

Our phantom was composed of 4 independent 2D slices which were placed juxtapose to form a 3D phantom. Each 2D slice represented a transverse slice through the brain (derived from PET images of a transverse section). In order to facilitate the calculation of quantitative parameters (e.g. modulation transform function, contrast, resolution and uniformity), cold and hot objects of different shapes and sizes (e.g. circle, triangle, and rectangle) were embedded to the slices. Plexiglas sheets of different sizes were provided to create and control inter-plane scatter.

The 2D slices could have been placed at different distances with or without the scattering media (Plexiglas sheet). There are various compartments which were separately filled with varying amounts of radiotracer to simulate a variety of "hot" and "cold" abnormalities. The phantom was principally designed to provide the data for evaluations of reconstruction techniques via calculation of quantitative parameters. Four slices of the phantom are shown in figure 1.

The first slice (figure 1A) intended for the calculation of Modulation of Transform Function (MTF). The second slice (figure 1B) is designed to assess the image resolution. The uniformity of an image may be evaluated using the third slice (figure 1C). The last slice (figure 1D) provided a realistic representation of the human brain, in terms of the physical dimensions, the gray-to-white tissue layout, ventricle contents and relative uptakes. The latter slice simulates the gray-to-white tissue uptake ratios of 2:1 to 4:1. The ventricles which were normally void of radioactivity were also fabricated. The blueprint of the phantom was made using Corel Draw 12, then it was transformed on acrylic sheets of 8 mm thickness and snipped with laser cutting system. During the research, the design of the phantom was modified several times.

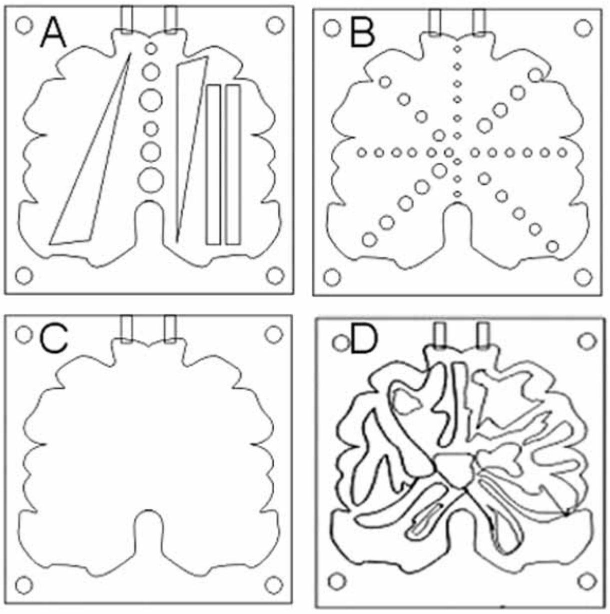

Figure 1. Transverse 2D view of the phantom; A) first slice, B) second slice, C) third slice, D) fourth slice. They are placed juxtapose to form the 3D configuration.

Due to huge amount of calculation required in quantification of the several images, and also to avoid operator dependency, software was developed to accompany the phantom. The software was developed in MATLAB 7. All data in all conventional formats were provided, and all the required calculations in the requested range by the operator were performed; the results were then typed in excel format.

In order to evaluate the phantom and companion software, images from a dual head gamma camera SPECT system was used (Mediso, Nucline TM), which was equipped with low energy, high-resolution, parallel-hole collimator. Energy window was set at ±20% of photo-peak. The phantom was imaged two times. Each 2D phantom were imaged separately at 0-15 cm distances from the collimator face acquiring 10 millions counts in 128×128 matrix size.

The 2D phantom was placed juxtaposed to montage the 3D conformation. The phantom in 3D arrangement was imaged acquiring 128 views of 128×128 matrix size each in 20 seconds. The imaging was repeated with 1, 2 and 3 cm thickness Plexiglas sheets as scattering media.

The resultant images were transformed into interfile format and transferred to a personal computer. All images processed using the dedicated companion software.

Different filters and different filtering conditions were considered and the data were reconstructed (figure 2). Totally 4400 sets of data were obtained for each SPECT slice image, and then compared with the corresponding 2D images. For each slice the optimum reconstruction was determined. The criterion for selection of best image was maximization of the universal image quality index (UIQI) [7].

The following filters and filtering condition were considered in this investigation;

a) Metz (PSF FWHM = 3.5, 4, 4.5, 5, 5.5, and 6, order = 3, 6 and 9)
b) Butterworth (cut off = 0.2, 0.25 ,0.3 ,0.35, and 0.4, order = 2, 4, and 8)
c) Hanning (cut off = 0.3, 0.35, 0.4, 0.45 and 0.5)
d) Wiener (PSF FWHM = 4, 4.5, 5, 5.5 and 6).

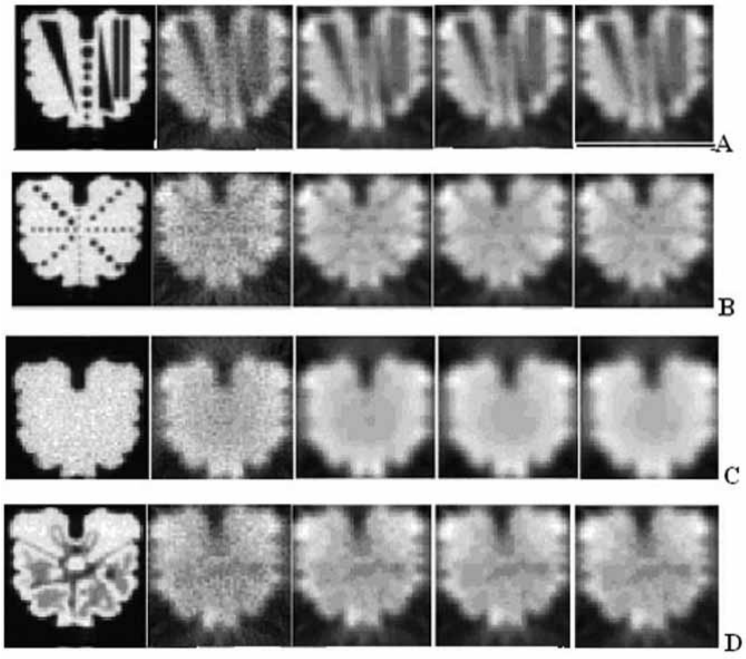

Figure 2. Different filtering conditions were evaluated for the four slices of phantom. Top to button: different slices of the phantom. Left to right: the first column is the reference images and the rests are the optimum image obtained with the Wiener, Metz, Butterworth and Hanning filter respectively. All filter produce images of acceptable quality in their optimum condition.

RESULTS

It was observed that under no circumstance the quality of a reconstructed slice image could be better than the corresponding planar image of the slice; therefore the planar images of the 2D phantoms were used as the most perfect images which could have been obtained in ideal reconstructions. The difference between the reconstructed slices and corresponding planar images were assumed to be due to demerit impaired procedures (software quality). The assumption is quite valid, since both the planar and the reconstructed images were quite similar in all aspects related to the hardware. So, it was concluded that any observed difference could have been due to imperfect reconstruction.

Probing different reconstruction conditions, the most similar reconstructed images to the corresponding reference images were determined in terms of UIQI. The most suitable filter and filtering condition were determined for each slice. The results of comparison are summarized in table 1.

DISCUSSION

The extent and distribution of the noise in the tomographic images are very much dependant on the method of reconstruction being used. The problem of noise in the SPECT is usually handled with the application of low-pass filter to suppress high frequencies components of the data. Selection of the suitable filter and

Table 1. The average of UIQI ± standard deviation obtained in optimum condition of filtering for each filter tested. Maximum value of UIQI is theoretically one.

Filter	First slice	Second slice	Third slice	Fourth slice
Hanning	0.255±0.03	0.224±0.03	0.216±0.02	0.199±0.02
Butterworth	0.266±0.02	0.231±0.02	0.221±0.03	0.212±0.02
Metz	0.279±0.03	0.237±0.02	0.218±0.02	0.226±0.02
Wiener	0.282±0.02	0.241±0.02	0.228±0.02	0.227±0.03

proper adjustment of the filter parameters have been an important issue since the introduction of tomographic imaging in nuclear medicine. Though much work has been done, there is no agreement about the optimum reconstruction technique. To some degree the discrepancy is acceptable due to variation in image quality and signal-to-noise ratio; however, the main obstacle has been the lack of a reliable quantitative technique for evaluation of reconstruction procedure.

We modified the Huffman brain phantom and introduced a simple technique which is useful in quantitative evaluation of reconstructed images. In this study, we have emphasized on the selection of a proper filter for reconstruction in backprojection technique. However the technique is potentially applicable for all types of processing.

Our observation showed that all the filters, tested at its own optimum condition, yields quite acceptable results. However, the mean UIQI in the Hanning filtered image is lower than the other filtered evaluated (table 1). The slope of the Hanning filters is relatively high and the filter gain drops below unity very quickly. Since the signal in nuclear medicine is mainly contained in the low frequency components, this fast drop-off is responsible for the low values of UIQI. The table 1 also reveals that the Metz and Wiener filters are better than the other filters evaluated. These filters are designed to eliminate the noise at high frequency and recovering the resolution lost during the acquisition. These results are quite in agreement with theoretical concepts that have not been experimentally proved before.

In conclusion the phantom and the companion software are very useful in determining the optimum filtering condition and reconstruction method. Our results also show that backprojection technique is potentially an acceptable technique of reconstruction.

REFERENCES

1. Stark IE, Woods PJ, Clark H (1983) Quality control of nuclear Medicine instrumentation. In: Mould RF (ed) London Hospital Physicists' Association, pp: 31-33
2. Bolster A (2003) Single photon emission tomography quality control in Quality control of gamma camera systems. York: Institute of Physics and Engineering in Medicine.
3. Hoffman EJ, Ricci AR, Yaner Stee LMAM, Phelp ME (1983) Hoffman multi-compartment 2-D brain phantom. ECAT-Basic design considerations. *IEEE Trans Nucl Sci,* ***30:*** *729-733.*
4. Frese T, Rouze NC, Bouman CA, Sauer K and Hutchins GD (2003) Quantitative comparison of FBP, EM and Bayesian reconstruction algorithms, including the impact of Accurate System Modeling for the IndyPET scanner. *IEEE Trans Med Imaging,* ***22:*** *258-276.*
5. Oconor MK (1976) Quality control of scintillation cameras, planar and SPECT US Department of Health, Education and Welfare (HEW) Publications.
6. O'conner MK, Hung JC (1999) Instrumentation quality control. In: The Mayo clinic manual nuclear medicine. USA Mayo Foundation publication, pp: 1-58.
7. Wang Z and Bovik AC (2002) A universal image quality index. *IEEE Signal Processing Letters,* ***9:*** *81-83.*