Impact of Reduced Acquisition Time on Bone Single-photon Emission Computed Tomography Images in Oncology Patients

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ABSTRACT

Background: The use of resolution recovery (RR) in bone and myocardial perfusion imaging is becoming increasingly popular in nuclear medicine departments. RR produces reconstructed images that show improved spatial resolution and signal-to-noise ratio compared with conventional single-photon emission computed tomography (SPECT) images. Objective: To evaluate the impact of the ordered subset expectation maximization (OSEM) RR modality on preserving noise, signal-to-noise ratio (SNR), and contrast-to-noise ratio (CNR) for short SPECT acquisition. Methods: This prospective study was conducted on 80 patients. Full SPECT acquisition was performed as a standardized protocol, while reduced acquisition was achieved with the Poisson resampling method. Noise, SNR, and CNR were measured for different reconstruction parameters for the same image levels. The impact of surface area and body mass index was also measured for the same reconstruction parameters. Results: The results show significantly higher SNR and CNR for the Evolution for Bone protocol compared to the other two reconstruction protocols for full and reduced SPECT acquisition. With the shortening of the SPECT acquisition, an increase in the value of noise was recorded. SNR and CNR decreased with the reduction in SPECT acquisition. Conclusion: The Evolution for Bone protocol for all three analyzed acquisition protocols had the lowest noise values. The highest SNR and CNR were recorded in the Evolution for Bone protocol for the three acquisition protocols and SPECT acquisition time can be reduced from 20 to 10 min for bone SPECT. Keywords: SPECT, SNR, CNR, OSEM, RR.

1. BACKGROUND

Radionuclide bone scanning is the most commonly used skeletal nuclear medicine imaging procedure. Introduction of single-photon emission computed tomography (SPECT) imaging has significantly increased the diagnostic sensitivity and specificity of planar bone scintigraphy. Compared with planar bone scans, SPECT methodology improves lesion detection during whole body scanning (1). The most common problem in SPECT is the potential for low signal-to-noise levels with degradation of image quality in cases of reduced injected activity or in fast SPECT acquisition. Furthermore, spatial resolution limited by the physical characteristics of the collimator and distance-dependent, degrading with distance from the detector. Since the introduction of emission tomography, filtered back projection (FBP) has been the main method for image reconstruction. The major manufacturers now offer image reconstruction with new methods based on the ordered subset expectation maximization (OSEM) with distance-dependent resolution modeling in commercial software (2).

The OSEM algorithm is a modified version of the maximum likelihood expectation maximization (MLEM) scheme, which divides the acquired projection data into subsets to reduce computational burden (3). Although MLEM allows modeling of various effects, such as scatter elimination, photon attenuation correction, and system response, the main problem of the basic MLEM algorithm is the increase in image noise...
for increasing numbers of iterations, mainly in low-count acquisitions (4). Resolution recovery (RR) methods consider the three-dimensional collimator response in image generation, reducing the effect of the point-spread function on image resolution. This method is very important when noise reduction is mandatory for maintaining or even improving image quality in low-count studies. A new commercially available iterative reconstruction (IR) algorithm that allows shortened acquisition time has been developed.

This new reconstruction software is validated for bone scans and SPECT myocardial perfusion imaging for a general-purpose SPECT gamma camera (5). Romer et al. also described OSEM RR methodology in various SPECT studies (6). The main reason for RR software incorporation in routine clinical practice is the increasing demand for SPECT studies, which increases pressure on nuclear medicine departments because of longer patient waiting lists. The RR OSEM reconstruction method incorporates the collimator detector response (CDR) into the reconstructed SPECT images by including the components of intrinsic response, geometric penetration, septal penetration, and septal scatter (7).

The main disadvantage of conventional SPECT in imaging metastatic bone disease is the extended acquisition time necessary to cover the required scan range. The main reasons for fast SPECT acquisition are to reduce the high incidence of artifacts caused by poor patient compliance during acquisition and to increase patient throughput in busy nuclear medicine departments. Therefore, the RR OSEM modality is the most important factor for producing images with higher spatial resolution and signal-to-noise ratio (SNR) than in conventional SPECT (8).

2. OBJECTIVE

The aim of the study is to evaluate the impact of the ordered subset expectation maximization (OSEM) RR modality on preserving noise, signal-to-noise ratio (SNR), and contrast-to-noise ratio (CNR) for short SPECT acquisition.

3. METHODS

This prospective study was conducted with 80 patients at the Clinic for Nuclear Medicine and Endocrinology of the Clinical Center University of Sarajevo (CCUS). SPECT or SPECT/CT study was conducted according to the standardized protocol of the Clinic for Nuclear Medicine and Endocrinology CCUS. Scan duration for the standardized SPECT imaging protocol was 15 s per frame. The images of the abbreviated acquisition were subsequently obtained by processing the full acquisition using the Poisson resampling software application (GE Healthcare Technologies, Milwaukee, Wisconsin, USA) to gain two new sets of images representing scan duration for 75% and 50% of the total scanning time. We used three different reconstruction protocols in order to measure the noise level, SNR, and contrast-to-noise ratio (CNR) in the original images and images with shortened acquisition time. These protocols were provided by GE Healthcare (Milwaukee, Wisconsin, USA). The reconstruction protocols were:

* Volumetrix MI for Oncology; OSEM iterative reconstruction-2 iterations and 10 subsets. 3D post-filter: Butterworth-cutoff frequency 0.48 and order 10.
* Evolution for Bone; OSEM iterative reconstruction-2 iterations and 10 subsets. 3D post-filter: Butterworth-cutoff frequency 0.48 and order 10 with Resolution Recovery.
* CDRC Evolution; OSEM iterative reconstruction-6 iterations and 10 subsets. 3D post-filter: Gaussian, 2mm full-width at half-maximum with Resolution Recovery.

In the original images and images with shortened acquisition time, the noise level, SNR, and contrast-to-noise ratio (CNR) were measured in the same anatomical area. The parameters listed above were measured for different reconstruction parameters, after which a statistical analysis of the measurement of noise, signal, and contrast changes in relation to the acquisition time was performed, and for different reconstruction programs. Body mass index (BMI) classification was used to determine the impact on noise level, SNR, and CNR at full and shortened acquisition for different reconstruction protocols. All patients underwent SPECT/CT imaging where we determined the body diameter based on CT imaging to calculate the impact on noise, SNR, and CNR for standardized and shortened SPECT acquisition.

This study was conducted according to the institutional research committee’s ethical standards and the 1964 Declaration of Helsinki. The clinical research ethics committee of the CCUS approved this study. Informed consent was obtained from all individual participants included in the study.

The results of descriptive statistical analysis are presented by the following parameters: mean ± standard deviation or median with interquartile range. The Shapiro–Wilk test was used to test the significance of the difference in deviation from the normal distribution. Category variables are represented by frequency as an absolute number or in percentages. Differences between groups were tested using the chi-square test. Quantitative variables between groups were tested by nonparametric Friedman test, if they are related samples, or Kolmogorov–Smirnov test between different samples. The results are presented in tables or graphs, and the accepted significance level is indicated by a p-value < 0.05. The Statistical Package for the Social Sciences version 26.0 (IBM Corporation, Armonk, New York) and MedCalc version 14.8.2 (Medcalc Software Ltd, Ostend, Belgium) were used in the statistical analysis.

4. RESULTS

Eighty oncology patients were enrolled in this study. Of these patients, 52 (65%) were male, and 28 (35%) were female. The average ages of female and male respondents were 61.93 ± 9.84 years and 69.88 ± 7.80 years, respectively.

A calculation adopted by the World Health Organization was used to measure the BMI (9). Of the female respondents, 7.1% were malnourished. Moreover, 21.4% of respondents had a normal body weight, and 10 respondents (35.7%) were overweight and obese. Of the male respondents, 1.9% of respondents were malnourished, and
32.7% had normal body weight. Moreover, 42.3% of respondents were overweight, and 23.1% were obese.

Using the CDRC Evolution MI protocol, by reducing the acquisition to 75%, there was no change in the average value of the SNR. By reducing the acquisition to 50%, the SNR decreased by 11.2%. Moreover, using the Volumetrix MI Evolution for Bone protocol, reducing acquisition to 75% reduces SNR by 8.6% in average SNR strength. By decreasing the acquisition to 50%, the SNR decreases by only 8.8%. Using the Volumetrix MI Evolution for Bone protocol, the SNR at 100% acquisition was 356.47, and by decreasing the acquisition, the SNR decreased. At the acquisition of 50% of the median, the SNR value was 278.01. Generally, Evolution for Bone showed the highest SNR for every scanning protocol, and SNR for Evolution for Bone 50% showed higher values compared to full scanning acquisitions in the other two protocols.

Using the CDRC Evolution MI protocol, reducing acquisition to 75% increases noise by 13%. By reducing the acquisition to 50%, a decrease in CNR by 10% in the average value is observed. Moreover, using the Volumetrix MI Evolution for Bone protocol, reducing acquisition to 50% shows a decrease in contrast by 8.7%. Evolution for Bone 50% showed higher average CNR compared to CNR of other two protocols at the average. Moreover, using the Volumetrix MI Evolution for Bone protocol, reducing acquisition to 75% increases noise intensity by 13.3% in average signal strength. Reducing the acquisition to 50% shows an increase in noise compared to average values by 44.4%. A significant difference for acquisition of 50% compared to a study of 100% for every reconstruction protocol was found at the level of p < 0.001.

Using the CDRC Evolution MI protocol, reducing the acquisition to 75% increases the CNR by 1%. By reducing the acquisition to 50%, a decrease in CNR by 10% in the average value is observed. Moreover, using the Volumetrix MI Evolution for Bone protocol, reducing acquisition to 75% reduces the CNR intensity by 8.5% in the average. Reducing the acquisition to 50% shows a decrease in contrast by 8.7%. Evolution for Bone 50% showed higher average CNR compared to CNR of other two protocols at the average. Moreover, using the Volumetrix MI Evolution for Bone protocol, reducing acquisition to 75% increases noise intensity by 13.3% in average signal strength. Reducing the acquisition to 50% shows an increase in noise compared to average values by 44.4%. A significant difference for acquisition of 50% compared to a study of 100% for every reconstruction protocol was found at the level of p < 0.001.

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According to the results for noise, SNR, and CNR depending on the size of the scanning area (Table 1), there is no significant difference in these parameters based on the scanning and reconstruction protocol. Evolution for Bone showed the best results for three scanning protocols regarding noise level, SNR and CNR in relation to the size of the scanning area.

Based on the analysis of the influence of BMI on noise, we found that there is no significant difference for the above mentioned parameters of scanning and reconstruction procedures. The impact of BMI on SNR showed no significant difference for acquisition duration and reconstruction parameters. CNR measurement compared to BMI also showed that there is no significant difference for acquisition duration and reconstruction parameters. Evolution for Bone showed the best results for three scanning protocols regarding noise level, SNR and CNR in relation to BMI (Table 2).

Since every patient received 740 MBq of Tc-99m HDP according to our standardized protocol, we believe with use of Evolution for bone we can lower the injected activity without affecting image quality no matter the size of the scanning surface or BMI.

5. DISCUSSION

It is possible to reduce SPECT scanning duration without degrading the image quality. Modern RR OSEM reconstruction protocols can maintain low noise values with a relatively slight decrease in SNR and CNR.

Borges-Neto et al. performed phantom and clinical studies to show new RR modality algorithms that can produce the same image quality for shorter scan times as for longer times (10). They created a new reconstruction protocol based on wide beam reconstruction (WBR). This new method was developed by the UltraSPECT company and is based on the IR modality with RR option. The authors performed measurements for full and half-time SPECT acquisitions for FBP, OSEM, and OSEM RR (WBR) reconstruction modalities in phantom and clinical studies. The results showed significantly higher signal and contrast for both the phantom and patients. Noise level values showed better values for the WBR protocol.

Various vendors now offer their reconstruction algorithm based on CDR modeling. These algorithms were primarily created for cardiac and bone SPECT studies. Arosio et al. evaluated a CDR software package from Johns Hopkins University Group that was implemented in Evolution for Bone software in a phantom study and in patient suspected of having bone infection (osteomyelitis, symptomatic orthopedic implants, or endovascular prosthesis) (11). Based on the literature results, IR proved to be better than FBP. The main aim of their study was to separate the effect of the CDR model from the effect of the OSEM reconstruction technique, both included in the Evolution for Bone software. They also compared acquisitions made using standard projection time with half-time acquisitions to evaluate possibility of RR in reducing the acquisition time without compromising image quality in clinical studies for detection of bone inflammation.

O’Mahoney et al. evaluated a specific OSEM RR (Astonish) modality designed for the Philips SPECT/CT for the conventional OSEM reconstruction algorithm (12). This study was conducted with a Jaszczak phantom. In this study, the authors also compared the OSEM RR with the conventional OSEM iterative algorithm for different types of collimators (LEGP and LEHR). They found that the Astonish algorithm gained higher spatial resolution with reduced partial-volume effects in smaller Jaszczak spheres. OSEM RR resulted in higher CNR values (image contrast) with lower levels of noise.

Many studies have highlighted the possibility of using the RR modality for improvement of SPECT images during IR. In the majority of cases, gamma camera producers supply nuclear medicine departments with generic processing stations for SPECT reconstruction protocols. During this modern era of PACS systems and independent reconstruction software packages, it is possible to use SPECT reconstruction software provided by a third-party supplier. Hay et al. (13) in their study showed that the application of RR significantly increased the image quality for bone SPECT reconstructions in comparison with the basic OSEM images. They also concluded that the RR modality implemented by an independent provider can improve image quality even when projection times are halved from 10 to 5 seconds. This short acquisi-
tion would not affect lesion localization or image quality.

Hughes et al. investigated the impact of the in-house-created Medical Imaging Research Group (MIRG) algorithm software based on the RR modality (14). They also investigated image quality, noise level, SNR, and CNR values for RR reconstruction modalities for the three major SPECT/CT vendors with their generic reconstruction software packages (Philips, Siemens, and General Electric Healthcare). This research has been conducted on the Thorax phantom for a series of specific acquisitions. In this study, the researchers concluded that there were no significant differences in image quality, noise levels, SNR, and CNR values for the MIRG RR OSEM protocol and three specific reconstruction protocols. These results are very promising, regarding further use of OSEM RR algorithm for the specific SPECT and SPECT/CT cameras with no specific RR algorithms.

Half-time SPECT with the OSEM RR modality can eliminate the need for planar static images. The results of the study by Thientunyakit et al. showed that half-time SPECT provides better image quality especially for the pelvic region than multiplanar static images (15). The radiation burden for the nuclear medicine staff is smaller for half-time SPECT. The authors also concluded that OSEM RR used for half-time SPECT provided better CNR values than those of conventional tomographic OSEM or the FBP method, especially for planar images.

6. CONCLUSION

By shortening the duration of the acquisition, an increase in the value of noise was observed in all reconstruction protocols. The Evolution for Bone software protocol for all three analyzed acquisition protocols had the lowest noise values. The highest SNR and CNR were recorded in the Evolution for Bone protocol for the three acquisition protocols, and SPECT acquisition time can be reduced from 20 to 10 min for bone SPECT.

Based on the literature data of other authors, the use of the RR reconstruction modality to compensate for signal reduction due to shortening of the SPECT acquisition time has been proven to be important.

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