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SPECT imaging with off-set detector system: Comparison of sampling angles 2, 4 and 6 degrees

Yasuyuki TAKAHASHI,*,** Kenya MURASE,* Hiroshi HIGASHINO,**
Hideo KAWAKAMI*** and Isao KAWAMATA****

*Department of Medical Engineering, Division of Allied Health Sciences, Osaka Graduate Medical School
**Department of Radiology, Ehime Prefectural Imabari Hospital
***Department of Internal medicine, Ehime Prefectural Imabari Hospital
****Department of Radiology, Ehime Prefectural Iyo-Mishima Hospital

Purpose: We evaluated an off set reconstruction method for single photon emission computed tomography (SPECT), and compared it with the conventional on set reconstruction method, using sampling angles of 2, 4, and 6 degrees. ***Method:*** A triple-detector system was used. In the off-set acquisition, sampling angles of the opposite detector were shifted 1/2 of the sampling angles of 2, 4, and 6 degrees. For example, when projection data were acquired every 6-degrees (sampling angle = 6 degrees), the projection angles were at 0°, 6°, 12°, and 174° with one detector, and 177°, 183°, 189°, and 357° with the other, opposite, detector. The conventional on set reconstruction images were compared with an off set reconstruction for a pool phantom of uniform concentration, a hot rods phantom, a myocardial phantom, and a human study. ***Results:*** The off set reconstruction method was better at all three sampling angles. FWHM (mm) were 11.02 at off-set versus 11.17 at on-set (sampling angle 2°), 11.13 at off-set versus 11.48 at on-set (sampling angle 4°), and 11.24 at off-set versus 11.64 at on-set (sampling angle 6°), respectively. In human myocardium SPECT, visualization of the interventricular septum and cardiac cavity was improved. ***Conclusion:*** Off set reconstruction by means of filtered back projection will be an efficient sampling mode, having a larger number of effective projection angles.

Key words: filtered back projection, off set reconstruction, 360-degree projection data, SPECT

INTRODUCTION

RECENTLY, filtered back projection, in which the data for each projecting direction are subjected to convolution integration by means of a reconstruction filter, has been used as a practical reconstruction method in single photon emission computed tomography (SPECT).[1] This method is also used for reconstruction of X-ray CT, and adoption of the off set detector system, which shifts the sampling data by 1/2 pixel 0 and 180 degree positions in data sampling, improved spatial resolution. By this method,[2] effective sampling views can be increased without increasing acquisition time.

In this study, we applied this sampling mode for reconstruction of the SPECT and investigated its effectiveness, by employing sampling angles of 2, 4 and 6 degrees.

MATERIALS AND METHODS

SPECT apparatus and acquisition parameters

The SPECT system used was a GCA-9300A/UI equipped with low-energy high-resolution collimators (Toshiba Medical Systems, Tokyo, Japan). Data processors were also Toshiba, GMS-5500A/PI. The data were sampled in a continuous mode with a 128 × 128 matrix size and reorganized to a step and shoot mode (sampling angles, 2, 4 and 6 degrees). It took 15 minutes for data acquisition altogether. The radius of rotation was 210 mm, and

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For reprint contact: Yasuyuki Takahashi, Department of Radiology, Ehime Prefectural Imabari Hospital, 4–5–5, Ishii-cho, Imabari, Ehime 794–0006, JAPAN.

E-mail: i-y-taka@epnh.pref.ehime.jp

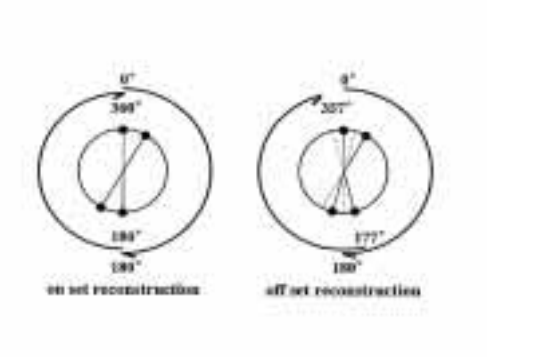

Fig. 1 In 360-degree acquisition at sampling angle of 6 degrees data are also present (*left*) on the 180 degrees opposite side of projection data in the conventional reconstruction, there are no opposed data (*right*) because each direction of data acquisition is shifted by 3 degrees in the opposite 180-degree area.

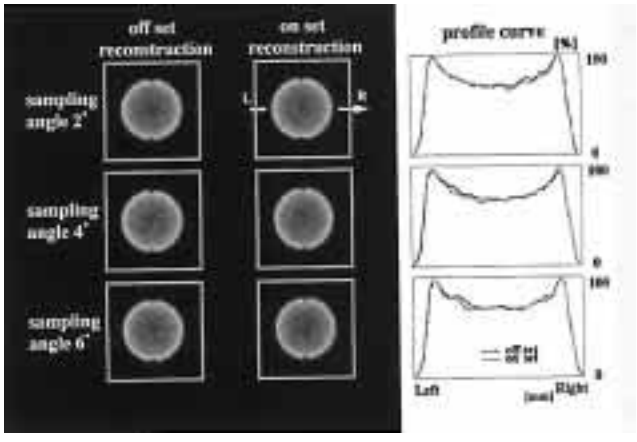

Fig. 2 The SPECT images and profile curves along the line obtained by the off set and on set methods in pool (uniformity) phantoms at the sampling angles of 2, 4, and 6 angles are shown.

attenuation and scattering were not corrected. The pre-treatment filter for the cylindrical phantoms was 5×5 normal, and a ramp filter was used for reconstruction of the SPECT. In both myocardial phantoms and the healthy subjects, Butterworth (order 8, cutoff frequency = 0.56 cycles/cm) was used as a pre-filter, and a Shepp & Logan filter was used for the SPECT reconstruction.

Reconstruction and analysis of SPECT images

When the sampling number of projection data is even, projection images are also present on the 180-degree opposite side in the conventional on set reconstruction method. In off set reconstruction, there are no opposed data because each direction of data acquisition is shifted by 1/2 of each sampling angle in the opposite 180-degree area.

For example, when reconstructed SPECT with 360-degree data sampling at 6 degree intervals, the projection data at the 0 and 180 degree positions are added and averaged by filtered back projection, and then projected.

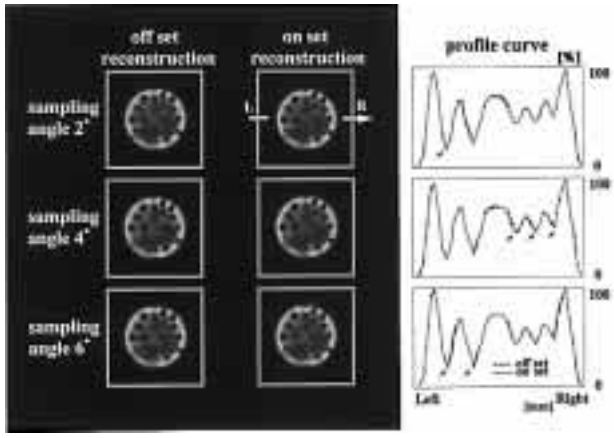

Fig. 3 The SPECT images and profile curves along the line (cold spot) obtained by the off-set and on-set methods in hot rods phantoms at the sampling angles of 2, 4, and 6 angles are shown.

Similarly, data using projection angles of 6 degrees and 186 degrees are combined in reconstruction. In the off set reconstruction method, opposite projection images were shifted 1/2 of the sampling angle, for example with a sampling angle of 6 degrees, the projection image at 177 degrees was used instead of the projection image at 180 degrees; and the image at 183 degrees was used instead of the image at 186 degrees, and so on.

In the present study, we applied the continuous acquisition mode and reorganized the sampling angles to 6 degrees. With one of the two detectors, we acquired the data twice; the first acquisition was from 0 to 180 degrees and the second acquisition was from 177 to 357 degrees; then we combined the two sets of 180-degree data for virtually 360 degrees (Fig. 1). To assess different sampling angles of 2 and 4 degrees, we compared the results obtained by off set reconstruction by a 1 or 2 degree shift in the sampling angle of 2 or 4 degrees, respectively (for a sampling angle of 2 [4] degrees: 0 to 180 degrees and from 179 [178] to 359 [358] degrees were combined). For the conventional on set reconstruction, projection data from 0 degree to 180 degrees and from 186 for a sampling angle of 6 degrees (184 and 182 for a sampling angle of 4 and 2 degrees, respectively) to 360 degrees were combined for 360 degree sampling.

Phantom study

The uniformity of the pool phantoms (set at conditions with a uniform radioactivity concentration), in which 185 MBq of $^{99m}TcO_4^-$ was injected, and the spatial resolution of hot rods phantoms with cold spots were evaluated visually and with the profile curves (mean ± SD, CV%). In the myocardial phantoms (RH-2 model, Kyoto Kagaku Co., Ltd.), a defect of 10 mm in diameter was created in the anterior wall to simulate an area of infarction. SPECT images were evaluated with short axis images (base,

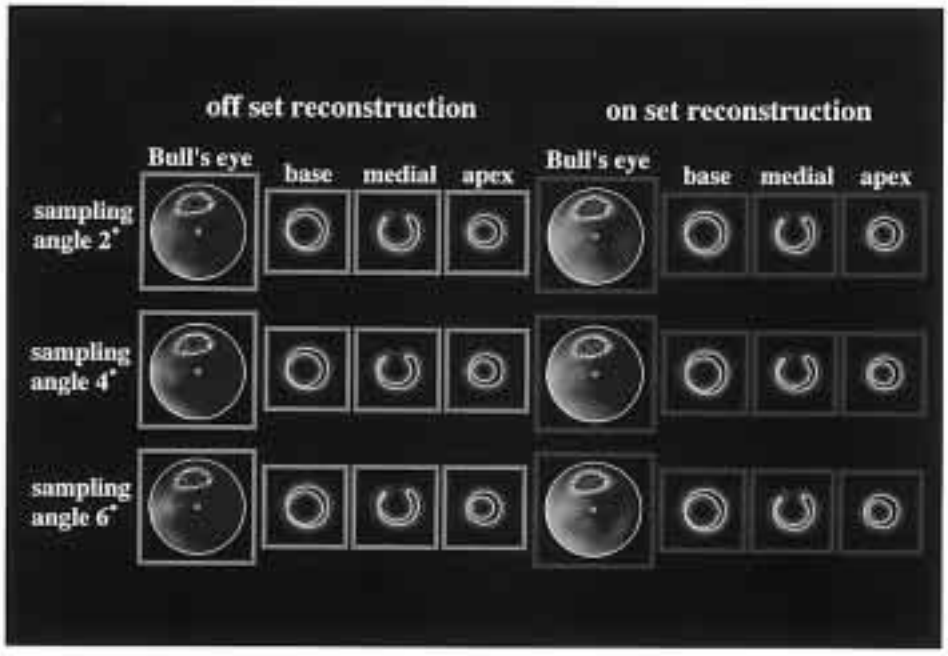

Fig. 4 Bull's eye map and short axis images of a myocardial phantom with an acrylic defect (10 mmϕ) in the anterior wall.

Table 1 Off-set reconstruction and on set reconstruction compare the SPECT image of pool (uniformed) phantom, hot rods phantom and myocardial phantom, and FWHM and SPECT are shown

	FWHM		SPECT values (phantom)					
	(mm)		uniformed (Mean ± SD)		hot rods (Minimum)		myocardium (Mean ± SD)	
	off set	on set	off set	on set	off set	on set	off set	on set
2°	11.02	11.17	86.73 ± 7.58	86.24 ± 7.90	45.9	46.2	86.38 ± 9.56	83.79 ± 8.75
4°	11.13	11.48	85.33 ± 7.40	84.72 ± 7.70	49.9	51.4	85.54 ± 9.83	83.25 ± 9.73
6°	11.24	11.64	83.00 ± 6.49	82.72 ± 7.38	53.1	55.7	84.25 ± 9.08	82.54 ± 9.99

medial, apex) and Bull's eye map.

Human study

Myocardial perfusion SPECT of a normal 32-year-old man was examined at 90 min after intravenous injection of 555 MBq of ^{99m}Tc-MIBI at rest.

Statistical analysis

The profile curve was used for evaluation of a pool (uniformed) and hot rods phantoms. The SPECT value (The maximum value was standardized with 100%: mean ± SD [CV%]) was used for evaluation of the myocardial phantom and the normal male (Bull's eye and short axis).

RESULTS

The FWHM of off-set and on set 6-, 4- and 2-degrees are summarized in Table 1. The FWHM of the off-set reconstruction was better than those of on-set reconstruction in all the three sampling angles.

Phantom study

The transaxial images and profile curves along the outlines of the pool (uniformed) phantom are shown in Figure 2. The SPECT values (mean ± SD [CV%]) are for the internal side at both ends of the transaxial image. The transaxial images of off set reconstruction were superior in terms of uniformity at any of the sampling angles. There were smaller variations in the SPECT values, and they were better at smaller sampling angles.

The transaxial images of the hot rods phantom and the profile curves along the lines set on the 19 and 13-mm cold spots are shown in Figure 3. The minimum SPECT values are shown in Table 1. Off set reconstruction of the transaxial images yielded lower minimum SPECT values.

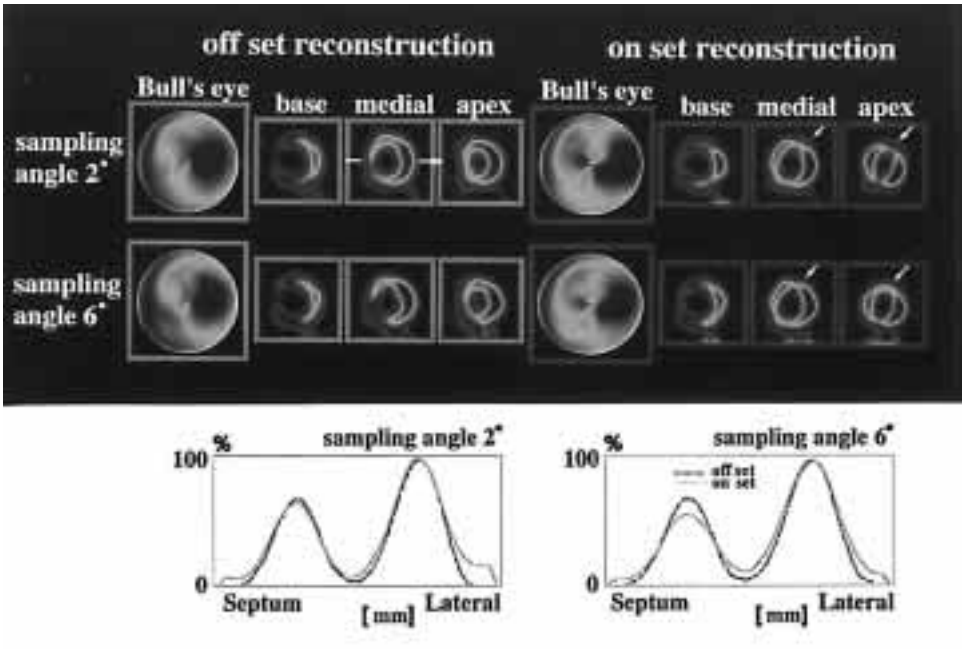

Fig. 5 Myocardial SPECT images 90 minutes after intravenous injection of 555 MBq of ^{99m}Tc-MIBI in a 32-year-old normal male. A profile curve on line in the medial area of the short axis image.

Off set reconstruction images of the myocardial phantoms showed fewer artifacts in the anterior and lateral walls, which was seen in the Bull's eye regional count values (without defect area, 23 divisions) (Fig. 4). Visualization of the defects was also better in off set reconstruction. The artifacts were mostly suppressed by off set reconstruction at the sampling angle of 2 degrees. The mean ± SD of the regional count map values is shown in Table 1 (right). Off set reconstruction yielded higher mean values and was better at all sampling angles.

Human study

In the normal male interventricular septum was visualized more clearly on off set reconstruction, as shown by the profile curves (arrows) at the center of the myocardium (Fig. 5). The minimum SPECT values in the cardiac lumen were lower than those of on set reconstruction (at a sampling angle of 2 degrees: 0.2 [off-set] vs. 5.7 [on-set], at a sampling angle of 6 degrees: 1.0 [off-set] vs. 9.1 [on-set]). In on set reconstruction at the sampling angle of 6 degrees, artifacts (count decrease) were observed in the middle portion of the anterior wall (arrows).

DISCUSSION

On SPECT imaging by means of filtered back-projection, the data are located 180 degrees opposite to the individual projection when the projection number is even, resulting in having the same directions. Therefore, the actual number of directions is a half of the number of projections. In other words, when sampling at an angle of 2 degrees, the number of projections is 180, and the number of directions is 90, when sampling at an angle of 4 degrees, the number of projections is 90, and the number of directions is 45, and when sampling at sampling an angle of 6 degrees, the number of projections is 60, and the number of directions is 30.

Cao et al.[3] simulated an even number of projection images to an odd number with the notice of sampling angles (number). For example, a 16 projection number was simulated to 15 or 17, 32 to 31 or 33, and 64 to 63 or 65. They suggested that an odd number would reduce the sampling angle to a half in comparison with an even number of projections, in which each opposite projection is back-projected for 360 degrees. In regard to odd numbers of projections, we have reported that data at sampling angles of 8 degrees are capable of yielding better SPECT images than data sampling at angles of 6 degrees, because the number of directions is 45, and the sampling time for each projecting direction increases.[4]

In this study, we focused on changing the projection number at even sampling numbers, such as sampling angles of 4 and 6 degrees, which are commonly used in the routine examinations. In our human study, as the projection number increased, visualization of the interventricular septum and cardiac cavity was improved. By on-set reconstruction, artifacts (aliasing artifacts[3]) in the anterior wall were observed, whereas the artifacts were not observed by the off-set reconstruction, in which the influence of counter-addition was reduced. This phenomenon suggests that attenuation may be less affected with the off set reconstruction, but further examination will be

necessary.

Although the 360-degree projection data were created by combining two sets of 180-degree projection data acquired separately, software should be able to prepare off-set reconstruction by using the continuous acquisition mode for clinical use. It will be reported later.

CONCLUSION

Off set reconstruction of the SPECT in filtered back projection is an efficient sampling mode, having a larger number of effective projection angles, resulting in better resolution and uniformity compared with the on set reconstruction.

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