Usefulness of Bremsstrahlung Images after Intra-arterial Y-90 Resin Microsphere Radioembolization for Hepatic Tumors

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Abstract

Purpose Y-90 resin microsphere radioembolization is used to treat inoperable hepatic tumors. After injection of Y-90 resin microsphere, the only method to visualize the distribution of Y-90 is the scintigraphic imaging of bremsstrahlung radiation. The purpose of this study was to evaluate the characteristics and usefulness of bremsstrahlung imaging in Y-90 resin microsphere treatment.

Methods Twenty patients (22 administrations) underwent intra-arterial Y-90 resin microsphere treatment. For pre-treatment planning, images of Tc-99m albumin macroaggregate (MAA) arterial injection and hepatic contrast

angiography were obtained. Post-treatment bremsstrahlung images were taken and compared with pre-treatment images. The extrahepatic activity was evaluated on bremsstrahlung images. To correlate the size and vascularity of the tumors with tumor visualization on bremsstrahlung images, the individual tumors were grouped according to visualization on each image and compared with one another by size and tumor-to-normal ratio.

Results All post-therapeutic bremsstrahlung images showed similar contours of the liver with pre-treatment angiography. No extrahepatic activity was seen in all cases. The visualized tumors on bremsstrahlung images were significantly larger than the non-visualized tumors. Tumor-to-normal ratios of the visualized tumors on bremsstrahlung images were significantly higher than those of the non-visualized tumors.

Conclusions Bremsstrahlung images after intra-arterial Y-90 resin microsphere treatment are useful in evaluating the intrahepatic distribution of radioisotope and detecting possible extrahepatic activity.

Keywords Y-90 · microsphere · Radioembolization · Bremsstrahlung · Hepatocellular carcinoma · Liver malignancy

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Introduction

Surgical resection or liver transplantation is the ideal curative therapies of the malignant hepatic tumors [1, 2]. Many hepatic malignant tumors cannot be surgically resected because they are locally advanced or involving both hepatic lobes at the time of diagnosis. A variety of therapeutic methods have been introduced for unresectable hepatic tumors, such as systemic chemotherapy, external

radiation therapy, trans-arterial chemoembolization, percutaneous ethanol injection, and percutaneous radiofrequency ablation [3–6].

Trans-arterial radioembolization using Y-90 labeled microspheres was introduced in the 1960s [7]. This method includes infusion of beta ray-emitting Y-90 labeled microspheres into the hepatic arteries so that the microspheres are delivered to the hepatic tumors [7–9]. Until now, two kinds of microspheres are clinically available: glass-microspheres (TheraSpheres; MDS Nordion, Ottawa, Canada) and resin microspheres (SIR-spheres; SIRTEX, Sydney, Australia) [10, 11].

Y-90 labeled microsphere radioembolization can provide a safe and effective therapeutic method for both hepatocellular carcinoma and metastatic hepatic tumor [6, 12–16]. In the randomized trial by Hazel et al. [12], among patients with hepatic metastasis of colorectal cancer, the group treated with combination regimen of chemotherapy plus single Y-90 microsphere administration demonstrated significantly increased therapeutic response and survival than the chemotherapy-only control group. Kennedy et al. [16] reported that in the group of patients with unresectable hepatic metastases from colorectal cancer who were refractory to previous treatments, a response to Y-90 microsphere radioembolization treatment occurred in 85% of patients, whose median survival was longer than the untreated or non-responding patients (10.5 months vs 4.5 months).

In addition to baseline angiography for evaluation of vascular anatomy, it is necessary to outline the possible distribution of microspheres for a successful treatment result with Y-90 microspheres. For this purpose, a Tc-99m albumin macroaggregate (MAA) hepatic angiography scan is done to determine the tumor vascularity, which is represented by the tumor-to-normal ratio, and to calculate the degree of shunting to the lung, and to detect any possible extrahepatic localization. Since 95% of Tc-99m MAA particles are within 10–100 μm in diameter, it can show a similar distribution to resin microspheres of $32 \pm 10 \mu\text{m}$ in diameter [17]. Using Tc-99m MAA pre-treatment imaging, the liver to lung shunt and extrahepatic regurgitation (e.g., stomach, duodenum and gallbladder) can be evaluated [18]. The required therapeutic activity of Y-90 microspheres can be calculated using a partition model, in which calculation of the tumor-to-normal ratio of radioactive microsphere distribution is needed [19].

It is necessary to know the actual distribution of Y-90 microspheres after administration into the hepatic artery, because intrahepatic distribution of radioactivity can predict the therapeutic effect, and unexpected adverse effects can be caused by extrahepatic regurgitation of microsphere distribution. Beta rays, however, can travel only 11 mm at maximum in human tissue, so they cannot be detected

easily. Interaction of beta particles with the tissue can produce bremsstrahlung radiation and this can be imaged with a gamma camera. This bremsstrahlung imaging is the only method to visualize the distribution of Y-90 in existence. But the usefulness of bremsstrahlung imaging has not been evaluated enough.

The purpose of this study is threefold: to identify the factors related to the different visualization of the tumors on bremsstrahlung and Tc-99m MAA images, to correlate the size of the tumor and visualization on bremsstrahlung images, and to assess the usefulness of bremsstrahlung imaging in identifying possible extrahepatic leakage.

Patients and Methods

Patients

From December 2008 to June 2009, 20 consecutive patients with primary or metastatic hepatic tumors that were not indicated for resection were enrolled this study. Patients who had distant metastasis, impaired hepatic function of Child-Pugh classification C, direct bilirubin more than 2.0 mg/dl, serum albumin less than 3.0 g/dl, or impaired renal function with serum creatinine more than 2.5 mg/dl were excluded from this study. Also, patients who had a history of external radiation therapy to the liver, systemic chemotherapy more than twice, and patients who showed more than 20% of the liver to lung shunt calculated using Tc-99m MAA images were excluded. This study was approved by the institutional review board of Korea University Hospital and informed consents were obtained from all patients who participated in the study.

Pre-treatment Tc-99m MAA Imaging

Hepatic contrast angiography for pre-treatment planning was performed in all patients. Immediately after hepatic angiography for evaluation of the hepatic vasculature and tumor location, 74 MBq of Tc-99m MAA was injected into the hepatic arteries with the catheter tip placed in the intended position for treatment. Two days to 2 weeks before therapeutic administration, sites of Tc-99m MAA injections were selected according to the intended administration locations. Following the intra-arterial injection of Tc-99m MAA, the patients were sent to the Nuclear Medicine Department and scintigraphic images of the chest and the abdomen were obtained by gamma camera (Infinia; GE Medical systems, Milwaukee, USA).

On anterior and posterior images of Tc-99m MAA, regions of interest (ROIs) were placed in the visually distinguishable intrahepatic tumors, the whole liver and the lung. The counts and pixel number for each ROI were

recorded. The liver to lung shunt was defined as the percentage of total counts of the whole lungs to total counts of the liver and the lung. The average count rate per pixel of the each tumor over the average count rate per pixel of the normal (non-tumorous) liver from each view was defined as the tumor-to-normal ratio. Possible extrahepatic radioactivity to the stomach, the duodenum and the gallbladder was evaluated.

Calculation of Y-90 Microsphere Dose

Y-90 microsphere activity for administration was calculated using a partition model that uses the tumor-to-normal ratio on Tc-99m MAA images, the volume of the targeted liver segments, and the volume of the tumor, according to the following equations [19]. From published decay data in MIRD format [20] the average energy released in the beta decay of Y-90 is $0.5385 \text{ Gy (GBq}\cdot\text{h)}^{-1}$, assuming that all of the energy of beta decay is absorbed in the tissue. Using the half life ($t_{1/2}=64.2 \text{ h}$), the total absorbed radiation dose after the complete beta decay can be calculated. When $A \text{ GBq}$ of Y-90 microspheres is evenly distributed in $M \text{ grams}$ of tissue, the absorbed radiation dose to the tissue is

$$\text{Dose(Gy)} = \frac{49670A(\text{GBq})}{M(\text{g})} \quad (1)$$

From Eq. (1), calculating the activity for infusion of resin microspheres was done by partition model;

$$A(\text{GBq}) = \frac{[D_{\text{liver}}(TNR \times M_T) + M_L]}{49670(1 - \frac{L}{100})} \quad (2)$$

where D_{liver} is the nominal dose (Gy) to the liver, TNR is the tumor-to-normal ratio, L is the shunt fraction (%) of microsphere from the liver to the lung, M_T is the mass of tumor, and M_L is the total mass of the liver.

And tumor-to-normal ratio ($T/N \text{ ratio}$) can be calculated as:

$$T/N \text{ ratio} = \frac{A_T/M_T}{A_L/M_L} \quad (3)$$

where, A_T is the activity in the tumor, A_L is the activity in the liver calculated from Tc-99m MAA images, M_L is the mass of the normal liver(excluding tumor), and M_T is the mass of the tumor [21].

Y-90 Microsphere Dose Delivery and Bremsstrahlung Imaging

On the day of the treatment, an intervention radiologist performed superselection of the hepatic artery, referring to pre-treatment hepatic angiography and Tc-99m MAA images, and then Y-90 resin microspheres were delivered through the catheter placed at the intended location of treatment.

Bremsstrahlung images of the abdomen were obtained using a gamma camera, 5–8 h after Y-90 microsphere delivery. An energy window was set at 55–285 keV and a medium energy collimator was used [22].

Analysis

Distribution of Y-90 on Bremsstrahlung Images

To verify the distribution of Y-90 resin microspheres to the targeted hepatic segments and the tumor, the bremsstrahlung images were compared with hepatic angiography images taken just before Y-90 resin microsphere delivery. Any radioactivity detected outside the liver was identified on the bremsstrahlung images. Possible complications caused by extrahepatic leakage of Y-90 were also evaluated.

Comparison of Visibility of Hepatic Tumors on Bremsstrahlung and Tc-99m MAA Images

We compared the visibility of the hepatic tumors seen on Tc-99m MAA images and bremsstrahlung images. To identify the factors related to tumor visualization on bremsstrahlung images, patients were divided into three groups in accordance with the tumor visualization on bremsstrahlung and Tc-99m MAA images. Group 1 consists of patients with same numbers of the visualized tumors on both bremsstrahlung and Tc-99m MAA images. Group 2 consists of patients with less visualized tumors on bremsstrahlung images than on Tc-99m MAA images. Group 3 consists of patients with no visualized tumors on both bremsstrahlung and Tc-99m MAA images. These three groups were compared with each other for tumor volume, number of the tumors, and tumor-to-normal ratio.

Correlation of Tumor Size and Vascularity with Visibility of the Tumor on Bremsstrahlung Images

We selected five tumors in each case in order of size, as measured in the longest dimension using computed tomography (CT), for evaluation of visibility on bremsstrahlung and Tc-99m MAA images. Each tumor was categorized into two groups, based on whether it was visualized on bremsstrahlung images or not. The longest dimensions of each tumor were compared between the two groups. Again, the size of the tumors was also categorized and compared in the same manner using Tc-99m MAA images. Each individual tumor was classified into three groups, according to agreement of visualization on two images. Group A consisted of the distinguishable tumors on both images. Group B consisted of the tumors that were visualized on Tc-99m MAA images, but not on bremsstrahlung images. Group C consisted of the non-visualized tumors on both

images. Additionally, the sizes were compared with each other. The tumor-to-normal ratio of each tumor was calculated on Tc-99m MAA images, and compared between visualized and non-visualized groups on bremsstrahlung images. In the non-visualized tumors on Tc-99m MAA images, tumor-to-normal ratios could not be calculated because an ROI could not be placed on those tumors.

Characteristics of Bremsstrahlung Imaging

The hepatic tumors contain more Y-90 microspheres than the adjacent normal parenchyma, so emits more bremsstrahlung radiation. The difference in Y-90 distribution in the tumor compared with the normal liver parenchyma (tumor-to-normal ratio) can represent effective microsphere concentration into the tumor, and this principle is the same with Tc-99m MAA. We evaluated the correlation of the tumor-to-normal ratio between Tc-99m MAA and bremsstrahlung images. To verify the proportional tendency between administrated Y-90 dose and amount of bremsstrahlung radiation from the liver, the total counts of the liver was calculated, and correlation between these counts and injected Y-90 dose was evaluated.

Statistical Analysis

Statistical analysis was done with commercial statistical software, SPSS for windows 10.0 (SPSS, Chicago, Ill., USA). The volume and number of tumors, and tumor-to-normal ratios between groups 1, 2, and 3 were compared using analysis of variance (ANOVA). The long diameters of the individual tumors were compared between groups A, B, and C by *t*-test and ANOVA. Tumor-to-normal ratios measurement between bremsstrahlung and Tc-99m MAA images were compared with *t*-test. The correlation between injected Y-90 dose and liver counts on bremsstrahlung images was analyzed by simple correlation. *P* values less than 0.05 were considered as statistically significant.

Results

Patients

A total of 20 patients were enrolled in this study. Two patients were treated twice, so a total of 22 administrations of Y-90 microspheres were performed. Eighteen patients were diag-

Table 1 Patient characteristics

No	Sex/age (years)	Diagnosis	Lung shunt (%)	Y-90 dose (GBq)	T/N ratio (MAA)	T/N ratio (Brem)	No. of tumors (MAA)	No. of tumors (Brem)	Group
1	F/77	HCC	4.44	1.80	2.18	1.49	1	1	1
2 ^a	M/71	HCC	4.84	0.92	3.35	1.13	2	2	1
3 ^a	M/71	HCC	4.84	0.69			0	0	3
4	M/53	HCC	5.14	0.28			0	0	3
5 ^b	M/59	HCC	7.94	2.97	4.17	1.48	10	2	2
6 ^b	M/59	HCC	7.94	2.08	4.17	1.25	10	2	2
7	M/42	HCC	9.07	2.86	3.38	1.61	10	2	2
8	M/55	HCC	6.16	0.40	3.01	1.46	4	1	2
9	M/76	HCC	9.99	0.89	6.07	1.36	3	1	2
10	M/72	HCC	4.31	1.08	1.86		3	0	2
11	M/63	HCC	6.49	0.81	3.94	1.31	1	1	1
12	M/56	HCC	5.71	0.67	2.25	1.14	2	0	2
13	M/64	HCC	8.44	1.70	2.51	1.46	5	1	2
14	F/69	HCC	4.70	0.52			0	0	3
15	M/70	HCC	3.78	0.98	2.80	1.49	2	2	1
16	M/79	HCC	5.68	0.79	2.98	1.30	1	1	1
17	M/66	HCC	1.86	1.35	7.99	1.14	5	2	2
18	M/64	HCC	6.68	0.23	3.31	1.29	1	1	1
19	M/53	Rectal cancer	5.96	2.04	2.19	1.27	5	3	2
20	M/84	HCC	5.67	0.81	3.52	1.59	3	3	1
21	M/73	HCC	8.08	1.47	2.64	1.57	2	2	1
22	M/55	Pancreatic cancer	4.38	1.23	2.53	1.20	4	2	2

^{a, b} Patients who received Y-90 SIR-sphere treatment twice

HCC hepatocellular carcinoma, T/N ratio tumor-to-normal ratio, MAA Tc-99m MAA images, Brem bremsstrahlung images

nosed as having primary hepatocellular carcinoma with clinical and histopathologic diagnosis, and the other two patients had the metastatic hepatic tumors, one from rectal cancer and the other from pancreatic cancer. Of 20 patients, 18 patients were male and two patients were female. The mean age of the patients was 65 ± 10 years. (Table 1)

Distribution of Y-90 in Bremsstrahlung

All 22 bremsstrahlung images showed identical intrahepatic distribution of radioactivity with pre-treatment hepatic angiography. There were no cases showing extrahepatic activity on bremsstrahlung images. These findings were

well matched with the absence of post-treatment complications related to the extrahepatic leakage of Y-90.

Comparison of Bremsstrahlung and Tc-99m MAA Images

Among the total 22 cases, three cases showed no distinguishable hepatic tumors on both bremsstrahlung and Tc-99m MAA images (13.6%, group 3) (Table 1, Fig. 1). In the other 19 cases, at least one hepatic tumor was visualized on both bremsstrahlung and Tc-99m MAA images. Among 19 cases, eight showed the same number of the hepatic tumors on both bremsstrahlung and Tc-99m MAA images (36.4%, group 1) (Fig. 2). In the other 11 cases, fewer tumors were visualized

Fig. 1a–c A hepatocellular carcinoma patient treated with 0.69 GBq of Y-90 resin microspheres to the left hepatic artery. **a** Pre-treatment hepatic angiography showed multiple small tumors in the left lobe. **b** Tc-99m MAA images showed no distinguishable tumor in the left lobe. **c** Bremsstrahlung images also showed no tumor in the left lobe

Fig. 2a–c A hepatocellular carcinoma patient treated by 0.89 GBq of Y-90 resin microspheres. **a** Pre-treatment angiography showed many tumors in both hepatic lobes. **b** Tc-99m MAA images showed only one tumor in segment four. **c** Post-treatment bremsstrahlung images also showed the same tumor

on bremsstrahlung images than on Tc-99m MAA images (50%, group 2)(Fig. 3).

Comparing groups 1 and 2, the number of the visualized tumors on Tc-99m MAA images were 1.4 ± 0.5 in group 1 and 5.5 ± 3.1 in group 2, so group 2 had more visualized tumors ($p < 0.005$). There were no significant difference in tumor-to-normal ratio and total tumor volume between the two groups (Table 2).

Factors Related to Tumor Visualization at Bremsstrahlung Images

The total number of the tumors was 66 in 22 case deliveries. The longest dimension of the visualized tumors

Table 2 Characteristics of three groups: patients with the same number of tumors on both Tc-99m MAA scan and bremsstrahlung images (*Group 1*), patients with fewer tumors on bremsstrahlung images than Tc-99m MAA scan (*Group 2*), and patients with no visible tumors on both images (*Group 3*) ($p < 0.005$)

	Group 1	Group 2	Group 3
No. of cases	8	11	3
Age (years)	72.6 ± 7.2	59.7 ± 9.4	64.3 ± 9.9
Sex (M/F)	7/1	11/0	2/1
Volume of tumors (ml)	101.6 ± 92.2	318.6 ± 335	9.8 ± 5.3
No. of visible tumors	$1.4 \pm 0.5^*$	$5.5 \pm 3.0^*$	0
Tumor-to-normal ratio	3.1 ± 0.6	3.6 ± 1.9	
Injected Y-90 dose (GBq)	0.98 ± 0.47	1.57 ± 0.85	0.49 ± 0.21

Fig. 3a–c A patient with hepatocellular carcinoma was treated with 1.08 GBq of Y-90 resin microspheres. Hepatic angiography (**a**) and Tc-99m MAA (**b**) images showed two or three tumors in the right lobe, but the post-treatment bremsstrahlung images (**c**) showed diffuse distribution of radioisotope and no distinguishable tumor

on bremsstrahlung images was significantly larger than for the non-visualized tumors (4.6 ± 2.0 cm vs 1.9 ± 1.1 cm, $p < 0.001$). The difference in mean diameter of the tumors between these groups on Tc-99m MAA images also showed a similar difference (4.1 ± 2.0 cm in the visualized group vs 1.4 ± 0.6 cm in the non-visualized group, $p < 0.001$) (Fig. 4). According to the agreement of tumor visualization on both images, the individual tumors were classified into three groups. Group A consisted of 34 tumors, group B 13 tumors, and group C 19 tumors. The mean diameters of the tumors of groups A, B, and C were 4.6 ± 2.0 cm, 2.6 ± 1.2 cm, and 1.4 ± 0.6 cm, respectively. The sizes of the tumors of group A were significantly larger than those of groups B and C ($p < 0.005$);

Fig. 4 Difference of tumor size between visualized and non-visualized tumors on Tc-99m MAA and bremsstrahlung images ($p < 0.001$)

and the tumors of group B were significantly larger than those of group C ($p < 0.001$) (Fig. 5).

Tumor-to-normal ratios of the visualized tumors on bremsstrahlung images are significantly higher than those of the non-visualized tumors (3.0 ± 1.2 vs 2.1 ± 0.7 , $p < 0.05$).

Characteristics of Bremsstrahlung Imaging

To evaluate the characteristics of bremsstrahlung images, tumor-to-normal ratios of bremsstrahlung and Tc-99m MAA images were compared. In four cases, there was no visualized tumor and the tumor-to-normal ratio could not be calculated. So, except for these four cases, in 18 cases the mean tumor-to-normal ratio was 3.50 ± 1.47 on Tc-99m MAA images and 1.36 ± 0.16 on bremsstrahlung images. The tumor-to-normal ratios on Tc-99m MAA images were significantly higher than that on bremsstrahlung images ($p < 0.001$) (Fig. 6); and there is no significant correlation of tumor-to-normal ratios between bremsstrahlung and Tc-99m MAA images.

Total liver counts calculated on bremsstrahlung images were significantly correlated with injected Y-90 resin microsphere dose ($p < 0.001$).

Discussion

Beta radiation from Y-90 has a tumoricidal effect, but it also destroys the adjacent normal tissue equally, causing

Fig. 5 Comparison of tumor sizes among three groups of tumors (* $p < 0.005$, ** $p < 0.001$). *Group A*: tumors which are visualized on both Tc-99m MAA and bremsstrahlung images. *Group B*: tumors which are visualized on Tc-99m MAA images, but not on bremsstrahlung images. *Group C*: tumors which are invisible on both images

Fig. 6 Tumor-to-normal ratios of bremsstrahlung images and Tc-99m MAA images

various adverse effects to occur. Reported side effects of Y-90 microsphere treatment are pulmonary fibrosis, gastroduodenal ulcer and radiation cholecystitis [23–28]. These adverse effects are caused by extrahepatic leakage of Y-90 microspheres. To predict and prevent these side effects, pre-treatment simulation imaging is necessary using a radiopharmaceutical of similar size to Y-90 microspheres. After treatment, it is necessary to assess the extrahepatic distribution of Y-90 microspheres for possible extrahepatic leakage, so post-treatment imaging of Y-90 distribution is needed.

Since the 1980s, bremsstrahlung imaging has been used clinically to assess the distribution of therapeutic beta-emitting radionuclides such as P-32, Sr-89 and Y-90 [29, 30]. The beta particle emitted from Y-90 is decelerated while it goes through adjacent atoms. Decreased energy during this process appears as a photon, i.e. bremsstrahlung radiation [31]. Eighty-six percent of all photons of bremsstrahlung radiation have energy within 50–390 keV and imaging of this radiation can be done with a gamma camera [22]. In Y-90 microsphere treatment, the purpose of bremsstrahlung imaging is to evaluate the intrahepatic or extrahepatic distribution of Y-90 after injection. Sporadic cases of tumor visualization at the bremsstrahlung imaging after Y-90 microsphere treatment have been published [32, 33]. To our knowledge, there has been no comprehensive analysis about the characteristics of bremsstrahlung imaging with statistical methods.

In this study, bremsstrahlung images visualized the same number of tumors as Tc-99m MAA images in 36.4% of cases; in 50% of cases bremsstrahlung images visualized fewer tumors than Tc-99m MAA images. The group of patients with the same numbers of the visualized tumors on both images (group 1) had significantly fewer tumors than

the group of patients with fewer visualized tumors on bremsstrahlung images compared with Tc-99m MAA images. In group 1, patients had one or two visualized tumors on Tc-99m MAA images, but in group 2, 91% of patients had more than three visualized tumors. These findings suggest that the smaller the size of the individual tumors, the fewer tumors are visualized on bremsstrahlung images.

Tumor-to-normal ratios on bremsstrahlung images have no significant correlation with those of Tc-99m MAA images. Tumor-to-normal ratios calculated with bremsstrahlung images ranged from 1.1 to 1.6, but the ratios with Tc-99m MAA images ranged from 2.18 to 7.99. This suggests that the scattering of bremsstrahlung radiation and the spill-over effect to adjacent pixels can degrade the resolution of the tumor images. Also, drawing the ROIs of the tumors on bremsstrahlung images was more difficult than on Tc-99m MAA images since the outlines of the tumors were vague. Ho et al. [19] found that tumor-to-normal ratios on both images had a significant correlation with one another, but this is quite contrary to our study. Patients enrolled in our study had tumors of smaller volumes than those patients enrolled in the study by Ho and co-workers. It is assumed that the spill-over effect may be more influential in our study.

Tc-99m MAA particles are known to have a similar size to Y-90 resin microspheres, and so are used for pre-treatment simulation. The size of Tc-99m MAA particles is, however, not exactly the same as Y-90 resin microspheres. While resin microspheres have a uniform size, Tc-99m MAA particles have a broader spectrum of the diameters [17]. These factors can cause a discordance of intrahepatic distribution between the two radiolabeled particles and affect the visualization of the tumors and tumor-to-normal ratios.

There was significant correlation between injected Y-90 dose and liver count on bremsstrahlung images. This demonstrates that bremsstrahlung imaging is a reliable method for post-treatment imaging of Y-90 resin microsphere therapy to confirm that adequate delivery has been achieved.

Y-90 is known as a pure beta-ray emitting radionuclide. It also, however, decays with pair production in very low probability (36×10^{-6}) [34]. Lhommel et al. [35] tried to detect positrons from this pair production and obtained positron emission tomographic (PET) images after intrahepatic injection of Y-90 microspheres. This Y-90 PET imaging takes a long time, due to the very small amount of positrons produced; however, it provides a better image quality and three-dimensional distribution of Y-90. So this method is very promising.

Conclusion

Bremsstrahlung imaging is a simple imaging technique with a planar gamma camera, and it can visualize the

intrahepatic and extrahepatic distribution of injected Y-90 microspheres. Bremsstrahlung imaging after intra-arterial Y-90 microsphere treatment is useful, in spite of poor image resolution.

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