COLLIMATION FOR IMAGING THE MYOCARDIUM

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Line-source response functions and modulation transfer functions (MTFs) were used to compare the resolution obtained with four myocardial-imaging agents: ^{129}Cs, ^{43}K, ^{13}N-ammonia, and ^{81}Rb with some ^{82m}Rb contamination. When an Anger camera with pinhole collimator was used, the order of decreasing resolution was ^{129}Cs, ^{43}K, ^{13}N, and ^{81}Rb. Two techniques were employed to determine the extent to which spatial resolution could be improved. The first, involving the addition of lateral shielding, improved the MTFs for all the agents studied. The second, which utilized a subtraction mode, gave the best overall results. With the second method the MTF curves for ^{129}Cs and ^{43}K became very similar and were superior to both ^{81}Rb and ^{13}N. Both techniques were found useful in improving the spatial resolution of certain myocardial-imaging agents by reducing or eliminating the effects of penetration of the pinhole collimator walls by high-energy photons.

Interest in myocardial imaging has been stimulated by the recent development of four cyclotron-produced radionuclides: ^{43}K, ^{81}Rb, ^{129}Cs, and ^{13}N (*1–4*). These cations chemically fall into Group 1 of the periodic table and can be categorized as "potassium analogs." They concentrate in the myocardium in proportion to blood flow and consequently produce negative images in regions of ischemia. Unfortunately, all these radionuclides emit medium- to high-energy gamma or annihilation photons, which are suboptimal for imaging. The principal photon energies and other pertinent physical characteristics are listed in Table 1. Theoretically, ^{129}Cs, with approximately 80% of its gamma photons in the 390–411 keV range, should be the most suitable agent for imaging with currently available instrumentation. However, cesium is probably the least reliable blood-flow indicator in this group, and ^{129}Cs is not generally available at present.

This study was carried out to determine if, by relatively simple means, collimator penetration and scatter from high-energy photons can be reduced sufficiently to provide images similar in quality to those obtained with ^{129}Cs.

MATERIALS AND METHODS

The spatial resolutions obtained with the above radionuclides were evaluated by line-source response function (LSRF) measurements and the calculated

Received Jan. 9, 1975; revision accepted April 10, 1975.

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TABLE 1. POTASSIUM AND POTASSIUM ANALOGS

Nuclide	Principal photon energies* (keV)	Abundance* (%)	Half-life	Relative photopeak efficiency†
^{43}K	371–394	103.0	22.4 hr	1.4
	590–610	94.0		0.7
^{129}Cs	372–411	71.0	32.1 hr	1.0
	548	5.0		
$^{13}NH_4$	511	200.0	10.0 min	1.9
^{81}Rb	446–511	90.5	4.7 hr	0.9
^{81m}Kr‡	190	64.5	13.0 sec	2.7
^{82m}Rb	511–554	109.2	6.3 hr	1.0
	619	37.5		
	698	23.6		
	777	75.6		
	828	25.0		
	1,044	29.0		
	1,317	26.0		
	1,475	17.0		

* Data taken from Refs. *7–11*.

† The abundance of ^{129}Cs photons with energies between 372 and 411 keV, multiplied by the photopeak efficiency for a 0.5-in.-thick NaI(Tl) crystal, was arbitrarily taken as 1.0. The tabulated values were calculated using data in Ref. *12*.

‡ Krypton-81m is an intermediate product in the decay of ^{81}Rb (*10*).

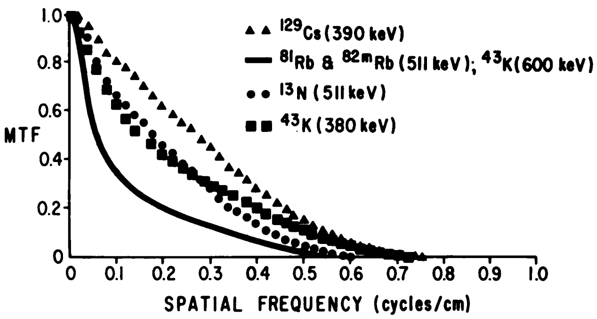

FIG. 1. Modulation transfer functions for ^{129}Cs, ^{43}K, ^{13}N, and ^{81}Rb with ^{82m}Rb, using Anger camera with pinhole collimator.

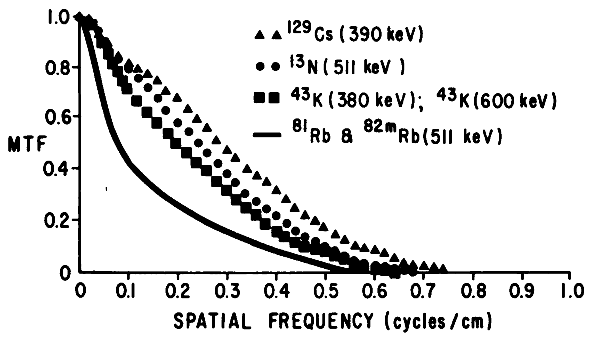

FIG. 2. Modulation transfer functions for ^{129}Cs, ^{43}K, ^{13}N, and ^{81}Rb with ^{82m}Rb, using Anger camera with shielded pinhole collimator.

modulation transfer functions (MTFs). For convenience ^{18}F was used as a substitute for ^{13}N. Because potassium analogs are distributed throughout the body, a 90-cm-long line-source was used to simulate the actual myocardial-imaging situation. The line-source had an inside diameter of 1.4 mm and an outside diameter of 1.9 mm. It was fitted in a 2-mm-square groove of a Plexiglas block, 90 $\times$ 40 $\times$ 2.54 cm, which served as backscatter material. A similar Plexiglas block was placed on top of the source to serve as absorptive and forward-scattering material.

A large-crystal scintillation camera (Dyna-Camera 2, Picker Corp., Cleveland, Ohio) with a pinhole collimator (10 mm aperture) was employed as the detector. Analyzer window widths of approximately 20% were centered on the photopeaks (for ^{43}K, data from the low-energy [380 keV] and high-energy [600 keV] photon peaks were collected separately). The distance from the line-source to the collimator face was 10 cm, the magnification factor at that distance being 1.64. Data for the LSRFs were obtained from the data processor using the ΔY mode. After background subtraction, MTFs were calculated using a modification of Cradduck's program (*5*).

For the second phase of the experiment, a shield was attached to the pinhole collimator before accumulating the data. This shield consisted of a lead plate, 63.5 $\times$ 38.1 $\times$ 1.27 cm, sandwiched between two steel plates, 63.5 $\times$ 38.1 $\times$ 0.32 cm. The shield contained a 9-cm-diam hole in the center to allow the end of the collimator to just pass through it and be flush with the bottom of the shield. The shield was directly fixed to the pinhole collimator by four long bolts and spacers.

Penetration of the collimator walls by high-energy photons was eliminated by a subtraction technique. After accumulating data with an unshielded pinhole, the data processor was placed in the subtract mode. A lead cone was then inserted into the tungsten aperture to prevent photons from reaching the detector without penetrating at least 3 cm of lead or tungsten. Counts were subtracted for a period equal to the original accumulation time, thus giving an ideal LSRF with negligible collimator penetration.

Except for the ^{81}Rb, the radionuclides were produced on-site (UCLA Biomedical Cyclotron). The following contaminants were found at the end of bombardment: for ^{129}Cs, 0.05% ^{22}Na; for ^{43}K, 17% ^{42}K; and for ^{18}F, 0%. The ^{81}Rb was obtained commercially (Medi-Physics, Emeryville, Calif.) and our analysis of the sample indicated that approximately 20% of the activity was ^{82m}Rb.

RESULTS

Using the conventional pinhole collimator, ^{129}Cs yielded the best spatial resolution of the radionuclides tested (Fig. 1). At spatial frequencies up to 0.25 cycles/cm, ^{13}N was slightly superior to ^{43}K (380 keV), but ^{43}K (380 keV) was somewhat better at higher spatial frequencies. At all spatial frequencies ^{43}K (600 keV) and ^{81}Rb with ^{82m}Rb were markedly inferior to the other two radionuclides.

As these results indicate, penetration of the collimator walls by high-energy photons was the probable explanation for the poor resolutions obtained with ^{43}K and ^{81}Rb with ^{82m}Rb. Accordingly, the measurements were repeated with a 1.27-cm-thick lead shield mounted on the pinhole to reduce wall penetration. The additional shielding added approximately 100 lb to the weight of the pinhole collimator, which was already heavier than the available parallel-hole collimators.* The results are presented in Fig. 2.

Although the MTF for ^{129}Cs was improved by less than 4% at all spatial frequencies, this radionuclide was still superior to all the others. As might be expected, ^{13}N exhibited a larger relative improvement and was better than ^{43}K at all spatial frequencies.

* In personal communication with Picker Corp. and Searle Radiographics, neither firm would guarantee the ability of commercially supplied units to support this added weight.

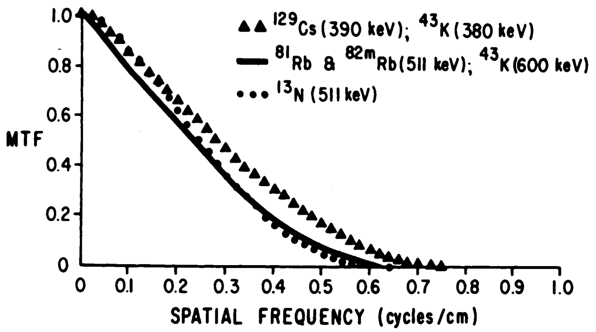

FIG. 3. Modulation transfer functions for ^{129}Cs, ^{43}K, ^{13}N, and ^{81}Rb with ^{82m}Rb, using Anger camera with pinhole collimator. Subtraction technique was used to eliminate effects of collimator penetration.

Rubidium-81 with ^{82m}Rb showed little improvement: clearly 1.27 cm of lead was not adequate shielding for the high-energy photons contributed by ^{82m}Rb. Reducing the amount of ^{82m}Rb present in a ^{81}Rb solution would alter this result.

The maximum amount of improvement, which might be expected if there was no collimator penetration, was determined using the subtraction technique. The MTFs of ^{129}Cs and ^{43}K (380 keV) were indistinguishable and superior to those of the other two radionuclides (Fig. 3). At spatial frequencies up to 0.3 cycles/cm, ^{13}N was slightly superior to ^{81}Rb with ^{82m}Rb and ^{43}K (600 keV), but at higher frequencies there were no significant differences.

DISCUSSION

These experiments indicate that when the pinhole collimator is used to image extended distributions of radionuclides emitting photons with energies greater than 400 keV, a significant loss in spatial resolution results. Limited experiments with a second commercial camera (Pho/Gamma HP, Searle Radiographics) and pinhole collimator gave very similar results. This general conclusion is of even greater importance in imaging the myocardium because only a small percentage of the injected radionuclide is in the field of view. Under the experimental conditions used, approximately 80% of the activity was outside of the field of view. The validity of this observation was shown in several clinical trials. Martin et al have recently reported the clinical use of a different arrangement for reducing collimator penetration for ^{43}K (*6*).

In conclusion, significant improvement in spatial resolution can be expected in myocardial images obtained with ^{43}K and ^{13}N by using additional shielding with the pinhole collimator. For ^{81}Rb with substantial amounts of ^{82m}Rb present, extensive additional shielding is needed to avoid severe image degradation. Even without ^{82m}Rb contamination, the spatial resolution for ^{81}Rb will not be better than that obtained with ^{13}N because photons of the same energy are being detected. When the distribution of these radionuclides does not change significantly with time, maximum improvement can be obtained through use of a subtraction technique.

From the standpoint of photopeak efficiency for an Anger camera, ^{13}N-ammonia was better than potassium or any of the other potassium analogs (Table 1).

ACKNOWLEDGMENTS

This work was supported by USAEC Contract AT(04-1) GEN-12 and USPHS Contract HV-12491. Computing assistance was obtained from the Health Sciences Computing Facility, UCLA, supported by NIH Special Research Resources Grant RR-3.

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