IMPROVED XENON IMAGES WITH ^{127}Xe

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We have investigated the use of a new xenon isotope, ^{127}Xe, for imaging studies. Xenon-127 should be superior to ^{133}Xe because of its higher photon yield per millicurie, better photon energy for imaging with the Anger camera, lower radiation dose to the patient per useful photon detected, and longer shelf-life. As expected, lung and brain images produced with ^{127}Xe appear superior to those produced with equal activities of ^{133}Xe. At present, ^{127}Xe is not generally available, but its production in large quantities is planned in the near future in the Brookhaven Linear Isotope Producer.

In the past we have experimented with the use of ^{133}Xe as a radionuclide imaging agent. Although others have used this agent successfully in conjunction with the Anger camera for ventilation and bloodflow studies (*1–6*), our results have been disappointing. Images produced on the conventional Anger camera using ^{133}Xe are of poor quality. This is due to several factors including (A) the relatively low photon yield of ^{133}Xe (35 photons/100 distintegrations) (*7*), (B) the low tissue penetration of the principal 81-keV photons, and (C) the overlap of the 81-keV photopeak with the scatter spectrum, limiting scatter rejection.

With the recent availability of a compact cyclotron (Cyclotron Corp., CS-15) at our institution, we have been able to investigate a more promising xenon isotope, ^{127}Xe. This radionuclide is produced by proton bombardment of a NaI target; the ^{127}I(p,n)^{127}Xe reaction yields 60–80 μCi/μA-hr at 15 MeV. (While the yield is low and thus suitable only for feasibility studies, substantial quantities should be soon available from the Brookhaven National Laboratory.) The potential utility of ^{127}Xe for cerebral blood studies has been discussed previously by Arnot, et al (*8*). We have investigated the use of ^{127}Xe for lung and brain imaging.

The physical properties of ^{127}Xe are summarized in Tables 1 and 2. The three major photon emissions have energies of 203 keV (65%), 172 keV (22%), and 375 keV (20%). We have chosen to use the combined 203–172-keV photon emissions in a single window for camera imaging. The combined emission of these two peaks is 87/100 disintegrations compared with 35/100 disintegrations for ^{133}Xe. In addition, it is important to consider the number of useful photons detected per unit radiation dose to the patient.

Xenon-127 decays by electron capture in contrast to ^{133}Xe which decays by β^- emission. Thus, the radiation dose to the patient from ^{127}Xe is substantially less per millicurie. The dose to the lung (from lung) per millicurie of inhaled gas is about 30% of that of ^{133}Xe (*9*). Using a gamma camera with ½-in. crystal and middle-energy collimator, the radiation

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TABLE 1. PHOTON EMISSIONS OF ^{127}Xe

Energy (keV)	Intensity (%)
203	65
172	22
375	20
145	4.2
58	1.4
28.5 (I x-rays)	~85

TABLE 2. PHYSICAL PROPERTIES

	^{127}Xe		^{133}Xe
Energy and abundance of principal scanning photons (% per 100 dis) (7)	203 keV (65%) 172 keV (22%)	87%	81 keV (35%)
Mode of decay	e.c.		β^- ($\bar{E}b = 110$ keV)
$d_{1/2}$ muscle	5 cm		3.9 cm
$T_{1/2}$	36.4 days		5.27 days
Dosimetry (9):			
mR/mCi/min (Lung ⟷ Lung)	1.5		5.1

dose per detected photon from ^{127}Xe is actually about ten times less than from ^{133}Xe.

The half-life of ^{127}Xe is 36.4 days, or approximately seven times that of ^{133}Xe. The longer physical half-life is an asset in terms of extended shelf-life and does not significantly affect the radiation dose to the patient since the biologic half-time of xenon is *relatively short* (less than 15 min for first and second $T_{1/2}$ biologic).

The tissue penetration of the major gamma photon emissions of ^{127}Xe is superior to that of the 81-keV photons of ^{133}Xe. The greater penetration of these photons not only gives higher counting rates per millicurie but also produces greater depth of the imaging field. This is especially important in cerebral studies since the calvarium is a significant absorber for the 81-keV photons of ^{133}Xe.

An additional advantage of ^{127}Xe over ^{133}Xe is improved intrinsic resolution in the Anger camera as illustrated in Fig. 1. Using a 30% window on the combined 203–172-keV emission peaks, one can readily see the ¼-in. lead bars with the ^{127}Xe source. These bars are not resolved when a ^{133}Xe source is used.

In tests of the clinical potential of this new isotope, a series of duplicate lung and brain scans was performed with ^{127}Xe and ^{133}Xe. These studies were carried out with the Pho/Gamma III version of the Anger camera (with bi-alkali tubes). In the first study (Fig. 2) a normal subject inhaled approximately 6 mCi of ^{133}Xe. A posterior lung view was obtained with the Anger camera (Pho/Gamma III) and the middle-energy diverging collimator. Approximately 100,000 counts were obtained in 3 min. The examination was then repeated on the same subject using 6 mCi of ^{127}Xe. The ^{127}Xe yielded 370,000 counts in the same 3-min collecting time, thus showing a 3.7 to 1 advantage in counting rate over the ^{133}Xe on an equal activity basis. The ^{133}Xe images were compared on both an equal time (1 and 3) and equal count (1 and 2) basis. The ^{127}Xe images appear superior in both cases. This suggests that higher photon yield, improved scatter rejection, and improved intrinsic resolution are available with ^{127}Xe along with a substantial reduction of absorbed radiation dose and no sacrifice of examination time.

A set of brain scans was also performed with both ^{127}Xe and ^{133}Xe (Figs. 3A and B). Again, 6 mCi were used for each study, and both were performed on the same subject using a middle-energy parallel-hole collimator. Each xenon isotope was introduced by inhalation with the subject rebreathing the radionuclide for approximately 15 min. The study with

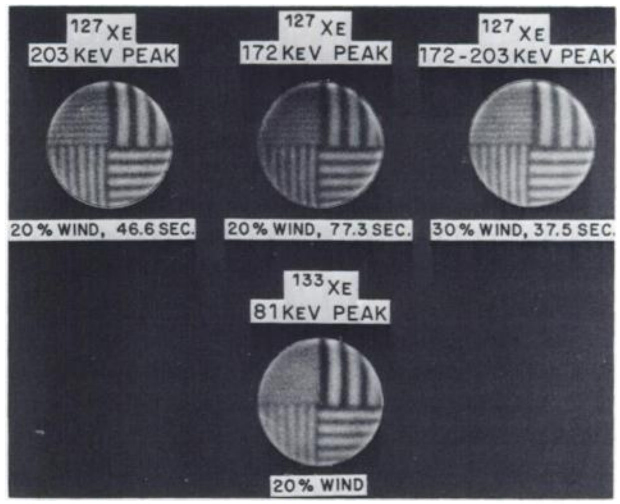

FIG. 1. Intrinsic resolution of Pho/Gamma III Anger camera is compared using ^{127}Xe at three window settings (top), and ^{133}Xe at one window setting (bottom). In each case, phantom with ¾, ½, ⅜, and ¼-in. lead bars was used as test object. Radionuclide source (1-liter globe) was placed 1 meter from face of uncollimated crystal. With ^{127}Xe, bar pattern is equally well visualized with single 203-keV window, single 172-keV window, or combined 203–172-keV window. Combined window is more efficient; in clinical situations, however, it results in poorer scatter rejection. In ^{133}Xe study, ¼-in. lead bars are totally obscured because of poor intrinsic resolution of Anger camera at energy of primary photon peak (81 keV). Each view was produced with 1,000,000 counts.

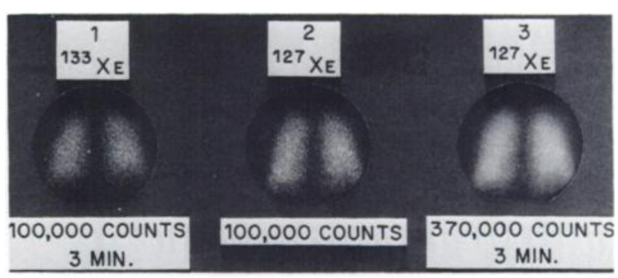

FIG. 2. Lung scan images produced with Anger camera (middle-energy diverging collimator). In each case, same subject inhaled 6 mCi of radioactive xenon gas. Three-min images demonstrate marked improvement in image quality with ^{127}Xe (3) compared with ^{133}Xe (1). The improvement is due to both higher photon yield and improved intrinsic camera resolution. Even with identical statistical content, however, ^{127}Xe image (2) is noticeably better than ^{133}Xe image. (All images were reproduced from magnetic tape storage on 256 × 256 matrix.)

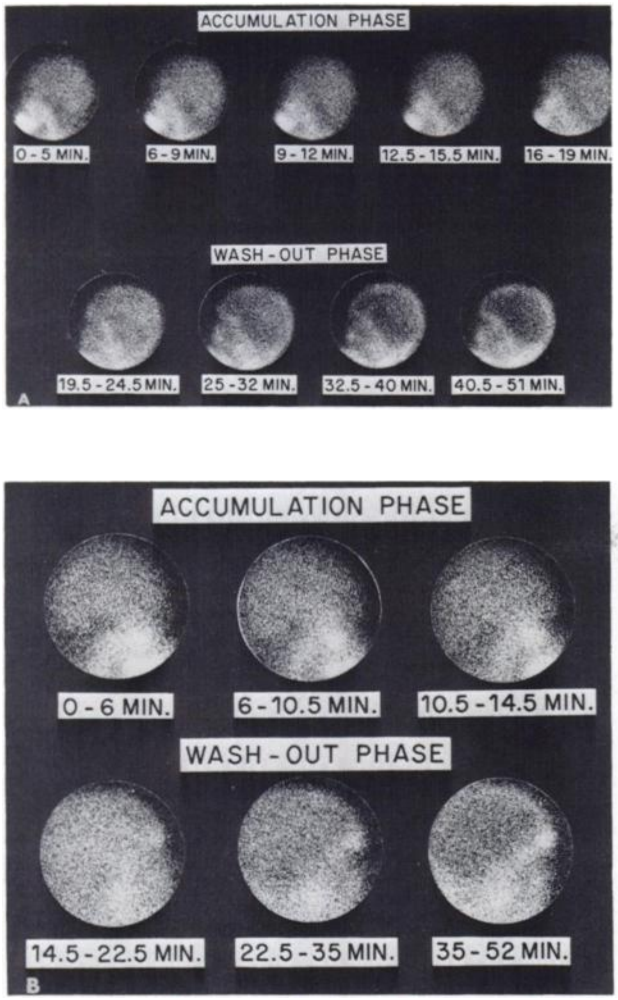

FIG. 3. (A) Sequential views of brain following ^{127}Xe inhalation (middle-energy parallel-hole collimator) demonstrating initial cerebral uptake followed by filling of surrounding calvarial and soft tissue structures. In washout phase, pattern is reversed. Activity in brain substance can be clearly demonstrated and visually distinguished from portion of calvarium and scalp seen on end (50,000 counts/image, left lateral view). (B) Same subject studied at later date with ^{133}Xe. General dynamics are redemonstrated. Image quality, however, is poor (50,000 counts/image).

^{127}Xe demonstrates improved image quality and less interference from calvarial and scalp activity.

DISCUSSION

Using pulse amplitude spectra obtained from a lung phantom with a ¼-in.-thick crystal, Arnot, et al (*8*) determined the percentage of the counts within the window due to radioactivity outside the collimator field of view. Their results are applicable to the scintillation camera since counts from radiation entering the detector through any particular collimator hole from radioactivity outside the field of view of that hole are attributed to scattered photons. With the baseline set at 91% of the photopeak energy, these contributions due to Compton-scattered photons are 14% for ^{127}Xe (for the 203-keV peak) and 26% for ^{133}Xe.

In the present study, a 30% window (163–212 keV) which included the 172- and 203-keV peaks was used. From the spectra for ^{127}Xe published by Arnot, et al (*8*), the measured contribution to this window from Compton scattering is approximately 21%. This estimate appears valid since Beck, et al (*10*) have shown that the fractional increase in photopeak counts from scatter depends primarily on the gamma-ray energy, source size, energy resolution, and baseline setting of the detector, and is virtually independent of crystal thickness and collimator resolution.

Technical improvements in imaging equipment, i.e., improved low-energy diverging collimators, and improved camera electronics should have the effect of improving the relative performance of ^{133}Xe.

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REFERENCES

1. Loken MK, Westgate HD: Evaluation of pulmonary function using xenon-133 and the scintillation camera. *Amer J Roentgen* 100: 835–843, 1967

2. Loken MK, Westgate HD: Using 133-xenon and scintillation camera to evaluate pulmonary function. *J Nucl Med* 9: 45–50, 1968

3. Medena JR, Lillehei JP, Loken MK, et al: Use of scintillation Anger camera and 133-xenon in study of chronic obstructive lung disease. *JAMA* 208: 985–991, 1969

4. Cannon PJ, Haft JI, Johnson PM: Visual assessment of regional myocardial perfusion utilizing radioactive xenon and scintillation photography. *Circulation* 40: 277–288, 1969

5. Honda J, Honda H, Torizuka K, et al: Serial brain scanning with radioactive xenon and scintillation camera. *Amer J Roentgen* 109: 701–706, 1970

6. Schibel EM, Landis GA, Moser KM: Inhalation lung scanning evaluation: Radioaerosol vs. radioxenon techniques. *Dis Chest* 56: 284–289, 1969

7. Lederer CM, Hollander JM, Perlman I: *Table of Isotopes*, 6th ed, New York, Wiley and Sons, 1968, p 72

8. Arnot RN, Clark JC, Glass HI: Investigation of ^{127}Xenon as a tracer for measurement of regional cerebral blood flow. *Proceedings of the 6th International Symposium on the Regulation of Cerebral Blood Flow (Cords)*, Ross Russell, RW, ed, London, Pitman, 1970

9. Dillman LT: Radionuclide decay schemes and nuclear parameters for use in radiation-dose estimation, Part 2. MIRD Pamphlet No 6, *J Nucl Med* 11: Suppl No 4, 27, 1970

10. Beck RN, Schuh MW, Cohen TD, et al: Effects of scattered radiation on scintillation detector response. In *Medical Radioisotope Scintigraphy*, vol 1, Vienna, IAEA, 1969, pp 595–616