BASIC SCIENCES

INSTRUMENTATION

Scintigraphic Imaging with Tantalum-178 and the Anger Scintillation Camera: Concise Communication

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Tantalum-178 is a short-lived radionuclide ($T_{1/2}$ = 9.3 min.) and emits primarily 56- to 64-keV characteristic x-rays. We have determined the imaging characteristics with this radionuclide and a large-field-of-view Anger camera. With a pinhole collimator, good spatial resolution is possible with Ta-178, although the image quality is superior with Tc-99m under comparable conditions. Spatial resolution with parallel-hole or converging collimators was much less satisfactory with Ta-178 because of septal penetration by high-energy photons. Pulmonary perfusion and liver-spleen images of excellent quality were obtained in the rabbit using the pinhole collimator and Ta-178-labeled agents.

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Tantalum-178, a short-lived radionuclide (half-life = 9.3 min), was developed initially for use with the multiwire proportional counter (*1,2*). Its attractive features—including its short half-life, the long half-life of its parent, (21.3-day tungsten-178), and the development of a generator with low breakthrough and high yield—make this radionuclide an attractive choice for many routine applications in nuclear medicine, provided that the limitations resulting from its low-energy photons (54–65 keV) can be overcome. We have therefore investigated the imaging properties of Ta-178 in phantoms and in animals using an Anger camera. We have compared these results with those obtained with technetium-99m.

METHODS

Tantalum-178 decays to stable hafnium-178 by electron capture 98.9% of the time, and 1.1% by positron emission. Electron capture results in a 61.2% branch to the ground state of Hf-178 and 33.7% to the first excited state at 93.1 keV. A 93.1-keV photon is emitted in 7.7% of the disintegrations. In 6.0% of the disintegrations, photons with energies greater than 500 keV are emitted. The photons that are useful for imaging with Ta-178 are the Hf-178 x-rays, which result from electron capture and the internal conversion associated with the 93-keV gamma transition (*1*). These x-rays are grouped about 56 keV and 64 keV, the average being 60 keV. The 93-keV photons are about 1/10 the intensity of the x-rays.

The gamma spectrum for Ta-178 was measured by connecting a multichannel analyzer to the y de-

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flection signal of a large-field-of-view gamma camera. Energy spectra were taken with the camera's energy range set for 80 keV and 500 keV first with a 4-mm-aperture pinhole and then with a low-energy, all-purpose collimator.

The spatial resolution of the system was measured with a pinhole collimator and Ta-178. Counts were acquired on a general-purpose computer. A capillary tube, 6-cm long and filled with Ta-178, was placed, in air, at 5, 10, and 15 cm from a pinhole collimator, and the line spread function was measured using the zoom feature on the computer. In addition, a liver phantom was loaded with 5 mCi of Ta-178. The phantom contained cylindrical defects (no activity) viewed on end by the collimator. The smallest cylinder had a diameter of 9 mm. Imaging was performed with the converging collimator (phantom at the collimator surface) and with the 4-mm pinhole collimator (phantom 3 cm from the aperture). Imaging was repeated with 1 in. of tissue-equivalent material interposed between phantom and collimator. One million counts were recorded on film.* The study was repeated with Tc-99m (5 mCi) again collecting one million counts per image.

The count-rate characteristics of the large-field-of-view camera were determined as a function of activity with a parallel-hole collimator (low-energy, all-purpose). A vial containing high-activity Ta-178 (sufficient to saturate the crystal) was placed on the surface of the collimator. Counts were collected for 75 min. A time-activity curve was plotted and compared with the decay curve of Ta-178. This procedure was repeated with the pinhole collimator (6-mm aperture) with the activity at the aperture.

To determine the feasibility of in vivo imaging with Ta-178, images were obtained in several animal species using a large-field-of-view Anger camera and a pinhole collimator (4-mm aperture) placed 2 cm from the animal. Tantalum-178 was eluted from the W-178 → Ta-178 generator and attached to either microspheres or minimicrospheres using a method that we have developed. An anesthetized albino rabbit was injected intravenously with 5 mCi of Ta-178-labeled microspheres. The pulse-height window (20%) was placed symmetrically over the 54–65 kev peak of the daughter's x-rays. Images of the lung were obtained in the posterior projection, acquiring 600,000 counts. Thirty minutes after the first injection, a second dose of 5 mCi of Ta-178-labeled minimicrospheres was injected. Images of the liver and kidney were obtained in the anterior projection. Three hundred thousand counts were acquired 2 min after injection.

To verify the relative merit of the pinhole collimator over parallel-hole collimators, imaging of the cardiac blood pool was performed in an anesthetized mongrel dog after the i.v. injection of 10 mCi of Ta-178 buffered with phosphate (2). Imaging was performed using the 4-mm pinhole collimator with the animal positioned in the left lateral position 3 in. from the aperture. Six hundred thousand counts were acquired. A second image was obtained 30 min later using the converging collimator (600,000 counts) following a new 10-mCi dose of Ta-178.

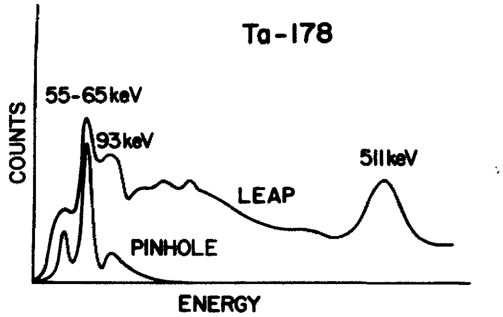

FIG. 1. Pulse-height spectra for Ta-178 with the pinhole and low-energy, all-purpose collimators.

RESULTS

The gamma spectra for Ta-178 for the pinhole and low-energy, all-purpose (LEAP) collimators are shown in Fig. 1. Observe that the high-energy (0.511–1.5 MeV) photons readily penetrate the LEAP collimator, whereas the pinhole collimator effectively eliminates most of the undesired high-energy events. The LEAP collimator is therefore inappropriate for imaging with Ta-178 on an Anger camera.

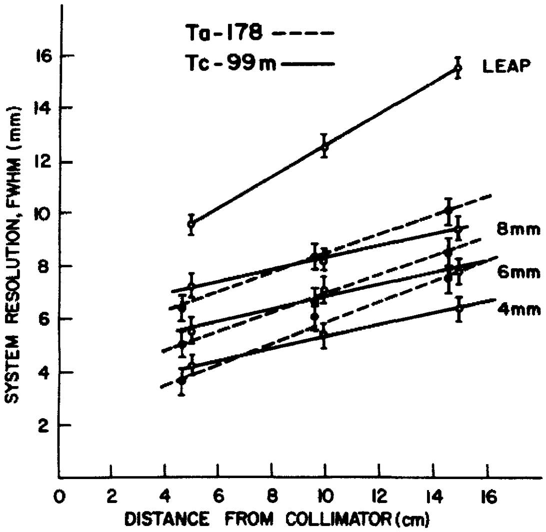

FIG. 2. Spatial resolution (FWHM) for Ta-178 and Tc-99m with the large-field-of-view camera and a pinhole collimator with 4-, 6-, and 8-mm apertures.

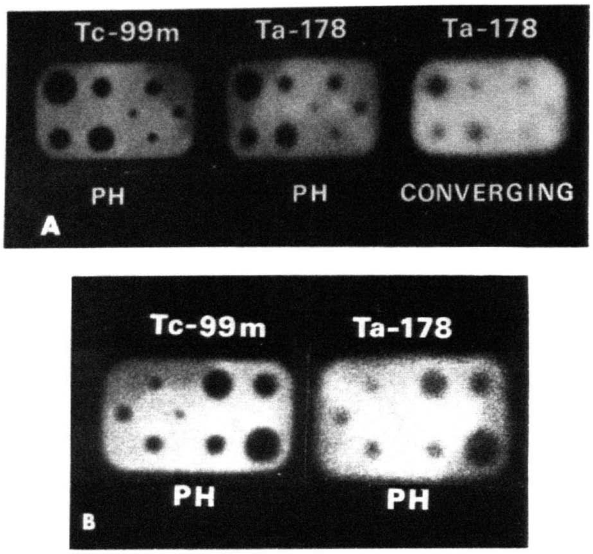

FIG. 3. (A) Images of liver phantom (in air) using Tc-99m and Ta-178 with pinhole (4-mm aperture) and converging collimators (1 million counts, 3 cm from collimator). (B) Liver phantom imaged with pinhole collimator (4 mm) using Tc-99m and Ta-178 (1 million counts, 3 cm from collimator with 2.5 cm of tissue-equivalent-material interposed).

The spatial resolution with Ta-178 for various pinhole collimators is shown in Fig. 2 and can be compared with Tc-99m. The resolutions (FWHM) for Ta-178 and Tc-99m are virtually identical for distances up to 10 cm from the collimator. At greater distances, the spatial resolution becomes increasingly better with Tc-99m. Images of the liver phantom were somewhat better with Tc-99m than with Ta-178, particularly with scattering material interposed between the collimator and the phantom (Fig. 3). Whereas all the defects could be visualized with Ta-178 and the pinhole collimator, there was more background activity caused by the high-energy photons and scattered radiation than with Tc-99m and the pinhole collimator.

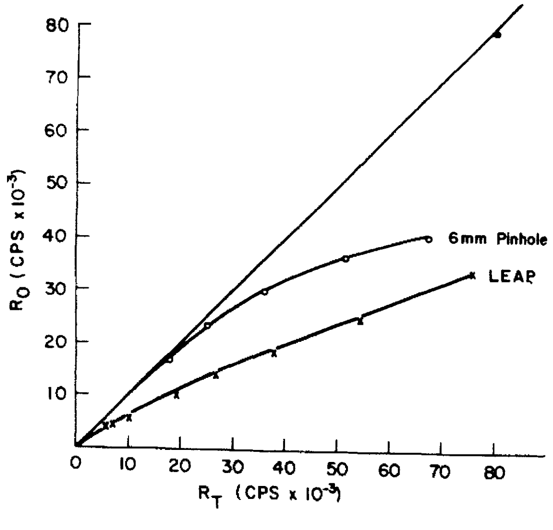

FIG. 4. Count-rate performance for large-field-of-view camera, pinhole and low energy, all-purpose collimators, and Ta-178. R_T = theoretical cps; R_0 = observed.

The count-rate performance of the detecting system is shown in Fig. 4. The line of identity is also shown. The count loss with a LEAP collimator is considerably higher because of the large number of detected high-energy photons.

Pulmonary perfusion and liver-spleen images of excellent quality were obtained from the rabbit using the pinhole collimator (Figs. 5 and 6). The cardiac blood-pool images in the dog, obtained with the pinhole collimator, were superior in quality to the comparable image using the converging collimator (Fig. 7).

DISCUSSION

Tantalum-178 is a short-lived radionuclide with useful physical characteristics for nuclear medicine (*1*). Tantalum-178-labeled radiopharmaceuticals for the imaging of the heart, the lungs, and the liver have been described (*2, 3*). Its 9.3-min half-life is short enough so that repeated injections can be administered during a patient's single visit to the clinical unit but is sufficiently long so that radiopharmaceuticals can be prepared. Its parent is tungsten-178, with a 21.3-day physical half-life. The W-178 → Ta-178 generator therefore has a long shelf life with a high yield of Ta-178 and with acceptably low breakthrough of the parent (*2*). There are, however, two limitations to scintigraphy with Ta-178 and conventional imaging equipment: a) the most abundant photons, the hafnium characteristic x-ways, have low energies (54-65 keV); and b) there is a small fraction (6.0%) of 511-keV and higher-energy photons, which result in scattered radiation.

We have demonstrated that good spatial resolution can be obtained using Ta-178, the large-field-of-view camera, and the pinhole collimator. Resolution in terms of full width at half maximum is comparable between Ta-178 and Tc-99m up to 10 cm from the collimator. The quality of the liver-phantom images was not as good with Ta-178 as with Tc-99m because of the more abundant scattered radiation with Ta-178, which results in slight degradation of edge resolution and increased background activity under comparable conditions.

The major reasons for the good spatial resolution with Ta-178 are that the pinhole collimator magnifies the image and minimizes the intrinsic degradation in camera resolution with low-energy pho-

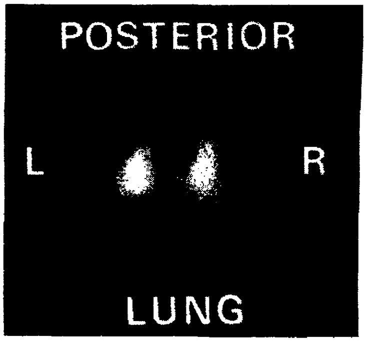

FIG. 5. Perfusion scintigram of rabbit lung after injection of Ta-178 microspheres (4-mm pinhole collimator).

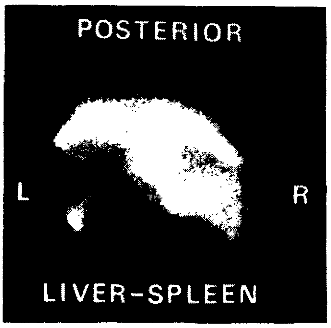

FIG. 6. Rabbit liver-spleen scintigram performed after injection of Ta-178 minimicrospheres (4-mm pinhole collimator).

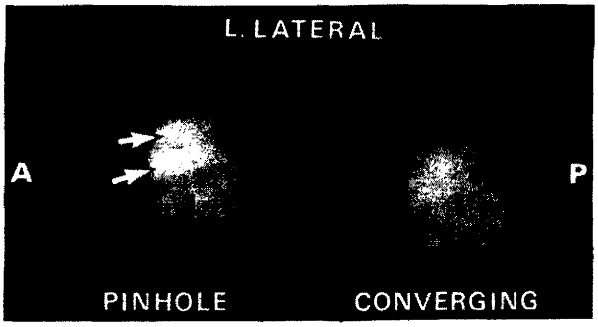

FIG. 7. Equilibrium blood-pool scintigrams performed after injection of Ta-178 in dog. Upper arrow = right ventricle; lower arrow = left ventricle; L = liver.

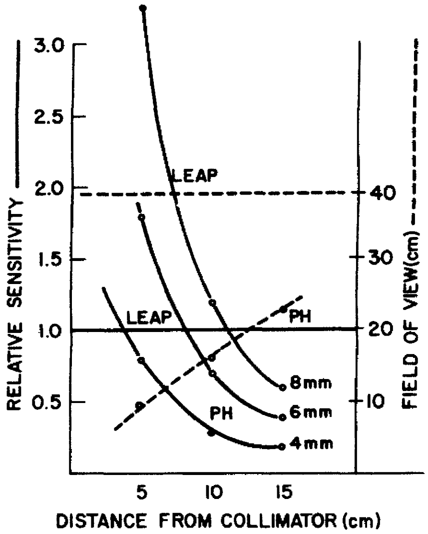

FIG. 8. Sensitivity and field of view (cm) of pinhole and low-energy, all-purpose collimators as a function of distance from collimator. (Calculated from data supplied in LFOV Handbook, Searle Radiographics.)

tons; it also provides adequate shielding to absorb the scattered radiation resulting from the high-energy photons. These photons are secondary to only 6% of the disintegrations, but they produce much off-target background through the penetration of the collimator's septa and the generation of scattered radiation. This results in unacceptable spatial resolution with standard low-energy collimators and the Anger camera. In addition, the high proportion of scattered radiation reaching the crystal with multihole collimators results in a severe count loss because of crystal saturation with only moderate radiation flux. The pinhole collimator, on the other hand, absorbs a high proportion of the high-energy photons, preventing interactions within the camera crystal that result in scattered radiation within the energy range of the pulse-height discriminator.

Since good spatial resolution can be achieved only with the pinhole collimator, practical applications are restricted to smaller organs such as the heart and to imaging in infants and children. Pediatric imaging with Ta-178 would result in a substantially reduced radiation dose to the patient because of the short half-life of Ta-178 relative to Tc-99m. The small body size would also result in a higher efficiency because of the reduced tissue attenuation relative to the adult.

Another potential application, first-pass emission angiocardiography with high temporal resolution, requires high count rates because all of the useful information is contained within four to six heartbeats (*3*). Large doses of short-lived Ta-178 could be injected, but clinical applicability depends on the relative efficiency of the pinhole collimator. At small distances between the organ and the collimator, the sensitivity is high (Fig. 8); at 5 cm, sensitivity with the 8-mm pinhole is 3.5 times that of the LEAP collimator. The field of view is only 9.5 cm at that distance, however. At 10 cm, the sensitivity is 1.2 times that of the LEAP collimator and the field of view jumps to 16 cm. The final answer as to whether these competing factors will permit Ta-178 angiocardiography with high temporal resolution must await studies in man.

FOOTNOTE

* Polaroid 107, Polaroid Corp., Cambridge, MA.

ACKNOWLEDGMENTS

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