Mobile Multiwire Gamma Camera for First-Pass Radionuclide Angiography

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In this paper, we describe a compact mobile multiwire gamma camera (MWGC) dedicated to first-pass radionuclide angiography (FPRNA). Studies with this camera are performed utilizing the short-lived ($T_{½}$ = 9.3 min) isotope tantalum-178 (^{178}Ta), eluted (up to 100 mCi doses) at the patient's bedside from a portable tungsten-tantalum generator. Processing is completed on-site within ~8 min, including calculation of right and left ventricular (LV) ejection fraction (EF), ejection rate, peak filling rate (PFR), and time to peak ejection and filling. Regional ventricular volume curves allow assessment of segmental ejection and filling indices. In a recent study, high count-rate FPRNA was performed before and during coronary angioplasty in the cardiac catheterization laboratory. During coronary angioplasty, a significant transient depression in LV function was seen: the LV EF fell from 52% ± 12% to 40% ± 14% (p = 0.0001) and the PFR from 2.4 ± 0.8 to 2.0 ± 0.8 EDV/sec (p = 0.0007). Thus, the mobile MWGC, combined with ^{178}Ta, expands the range of first-pass cardiac imaging. Imaging can now be conveniently used at bedside, during cardiac catheterization, and during coronary interventional procedures, allowing study of transient changes in ventricular function and possibly assisting in therapeutic decisions during emergency situations.

First-pass radionuclide angiography (FPRNA) is a very effective method of assessing right and left ventricular (LV) function. For many years FPRNA has been performed utilizing the multicrystal gamma camera and technetium-99m (^{99m}Tc). The development of a new improved, mobile multiwire gamma camera (MWGC) and refinement in the tungsten-178/tantalum-178 (^{178}W/^{178}Ta) generator provides several advantages over the conventional method of performing FPRNA. These include a higher count-rate, improved resolution, the ability to inject much larger doses of radionuclide, and the ability to repeat studies at frequent intervals. The study repetition is feasible due to the short half-life of ^{178}Ta (*1–2*).

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The purpose of this paper is to describe this new, portable MWGC, the improved technique to acquire and process FPRNA, and the new portable ^{178}W/^{178}Ta generator. The portability of the system allows studies to be performed at the patient's bedside anywhere in the hospital. In this report, we illustrate the use of the system in the catheterization laboratory.

MATERIALS AND METHODS

Multiwire Gamma Camera

The MWGC has a lightweight detector (23 kg), an onboard computer for imaging acquisition and processing, and a high resolution display for image processing and interpretation. The basic design of the wire chamber detector has been previously reported (*1*). The front of the detector (Fig. 1) is covered by a thin aluminum window through which photons penetrate to reach a system of wire grids, two cathodes, and one anode, in a gaseous mixture of 90% xenon (Xe) and 10% methane at 3 atm. We used a low energy, high sensitivity, parallel-hole collimator.

Events occur when the photons penetrate the aluminum window and enter the detection region where they interact with the pressurized Xe molecules. The resulting ions are then drifted into the detection region where they are collected at the anode. The charge is then amplified by a process of gas avalanche.

This system utilizes a high-speed delay line readout, which incorporates an event-pile acquisition system. The characteristics of the wire chamber detector are summarized in Table 1. This system is capable of delivering a peak count rate of 850,000 cps, which is four to five times the rate of the single-crystal camera. The sensitivity of our camera for ^{178}Ta was 36,200 cps/mCi and for ^{201}Tl it was 11,351cps/mCi.

The MWGC uses a 16 mHz 80286 CPU computer with a 10 mHz 80287 coprocessor. It is run by an MS-DOS 3.30 operating system. The software was designed based on technology developed at NASA and perfected in our laboratory at Baylor College of Medicine.

Figure 2 illustrates the overall size of the MWGC as com-

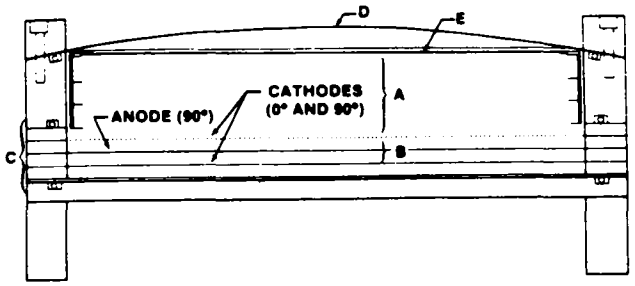

FIG. 1. Longitudinal diagram of multiwire gamma camera detector showing: (A) drift region, (B) detection region, (C) aluminum pressure vessel, (D) aluminum entrance window, and (E) negative high-voltage collection electrode.

TABLE 1. Characteristics of the Multiwire Camera

Peak Count Rate	850,000 cps
Spatial Resolution (30 to 80 keV)	≤2.5 mm FWHM
Intrinsic Image Uniformity	±5%
Detector Weight	23 kg
Detector Size	40 × 40 × 12 cm

pared to that of an echocardiography unit; its small size enhances the portability of the system. As is the case with the echocardiography device, the MWGC is light enough to be hand driven, without a need for a battery-driven motor. The MWGC can be rolled into any area of the hospital and easily positioned or maneuvered into tight spots.

The MWGC detector is supported by a telescoping arm, attached to a swivel column, which moves freely at the base of the camera (Fig. 3). Transportation of the multicrystal gamma camera requires great care in order not to damage the scintillation crystals. This is not a concern with the wire grid system used in the MWGC, which is very resilient.

Tantalum-178

FPRNA is performed using the short-lived, generator-produced ^{178}Ta ($T_{½}$ = 9.3 min). The generator is based on the parent isotope ^{178}W ($T_{½}$ = 21.5 days) which is cyclotron-produced (*2*). Tungsten-178 decays entirely by electron capture to ^{178}Ta, which then decays to stable hafnium-178 (^{178}Hf) by electron capture (99.2%) and by positron emission (0.8%). A schematic of the ^{178}W/^{178}Ta generator is shown in Figure 4.

Several improvements have been made in this system over the years (*3*). The current system utilizes a simple pushbutton operation which delivers a buffered isotonic dose of ^{178}Ta (1.1 ml) into a syringe placed on the outlet port. Buffer is required to adjust the eluant to pH 7.0.

These generators typically have a shelf-life of 30 days and can be used for many patient studies in a given day. Because of its short half-life, the build-up of ^{178}Ta occurs rather rapidly following each elution, i.e., after nine min the yield will be ~50% of the previous elution.

The short half-life of ^{178}Ta results in low whole body and critical organ radiation doses, which on a mCi per mCi basis, are ~1/20 those of ^{99m}Tc. This enables repeating several acquisitions within a short interval which is not possible when one uses technetium-99m (^{99m}Tc). The standard dose for Tc ($T_{½}$ = 6 hr) studies is 30 mCi, which is often divided between two 15-mCi injections of ^{99m}Tc (one given at rest, one during exercise). In contrast, doses of 100 mCi of ^{178}Ta per injection can be used repeatedly. The breakthrough of ^{178}W in these generators is maintained consistently below 10 μCi, thus, the contribution of ^{178}W to the radiation dose is negligible. The characteristics of ^{178}Ta are listed in Table 2.

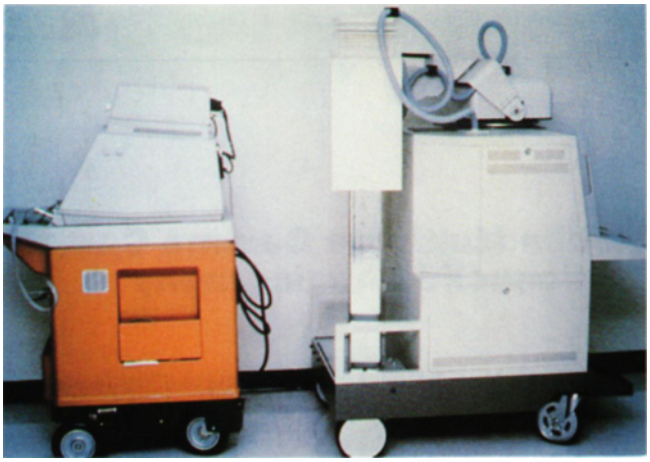

FIG. 2. Size comparison of multiwire gamma camera (right) to echocardiography machine (left).

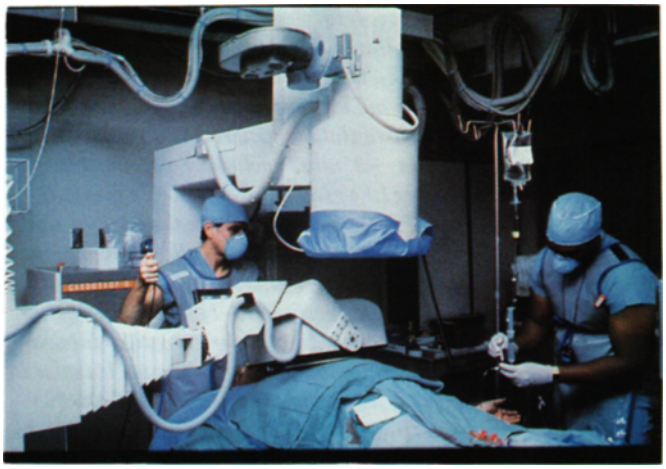

FIG. 3. Positioning of multiwire gamma camera in cardiac catheterization laboratory during first-pass study.

PATIENT POPULATION

The MWGC is presently designed for FPRNA. We illustrate the use of this system in the cardiac catheterization laboratory to assess LV function in patients undergoing coronary angioplasty. We studied 47 patients (36 male, 11 female, mean age 58 ± 17 yr) during 51 elective coronary angioplasties. Three patients underwent angioplasty of more than one stenotic lesion.

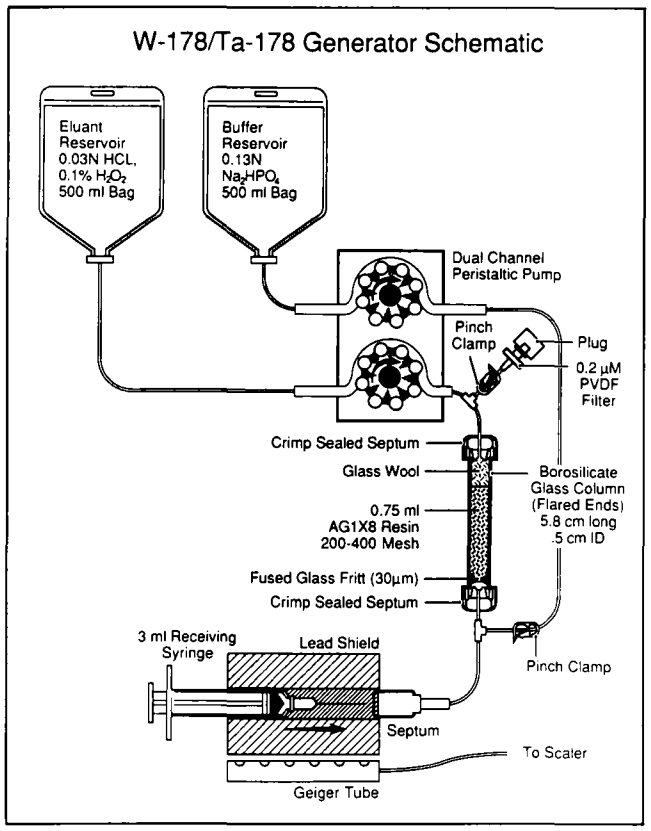

FIG. 4. Schematic of tungsten-178/tantalum-178 generator.

TABLE 2. Tantalum-178 Characteristics

Emission Energies	55-65 keV (85%) ≥511 keV (4%) 93 keV (6%)
Half-life	9.3 min
Patient Whole Body Dose*	1/20 Tc-99m
Patient Critical Organ Dose*	1/21 Tc-99m
Patient W-178 Whole Body Dose*	<0.2% of Ta-178 dose

* On a mCi per mCi basis.

Image Acquisition

A baseline first-pass study was acquired at the beginning of the procedure, prior to placement of the angioplasty catheter. The MWGC detector was positioned in the anterior projection just slightly to the left of the patient's midline. A dynamic first-pass acquisition was performed with ^{178}Ta injected as a bolus and flushed with 20 ml of normal saline, through a #7 Cordis sheath, which was placed in the femoral vein as part of the angioplasty procedure.

Data collection was begun just prior to injection and continued for 30 sec, with a frame duration of 25 msec. A 32 × 32 × 16 image matrix (0.75 cm/pixel) and a 30% energy window around the 60 keV peak of ^{178}Ta were employed. Data were stored directly on hard disk and archived to streamer tape and floppy disk.

After completion of the baseline acquisition, the angioplasty catheter was positioned in the coronary artery under fluoroscopy and the balloon inflated, thus transiently occluding the artery. We acquired a second FPRNA during coronary occlusion, using the same technique as for the first study, during the final 30 sec of a 1-min balloon inflation.

In order to facilitate our study, we placed the generator on a mobile cart and transported it to the catheterization laboratory (Fig. 5). Thus, we were able to perform both elution and injection at the patient's bedside, injecting from 15 to 80 mCi per elution. The exact dose was dependent on the time interval from the previous elution.

Imaging Processing

Analysis begins with an automatic check of the bolus. A region of interest is placed over the inferior or superior vena cava, followed by selection of the LV beats on the time-activity curve (TAC). Electrocardiographic gating was used to select the beats above 70% of the peak and define the end-diastolic frames. The lung background beat, which is automatically selected, is identified as the minimum point of the LV TAC. The software also allows for automatic determination of the valve plane utilizing phase analysis.

A first-pass transit of ^{178}Ta is shown in Figure 6. The figure

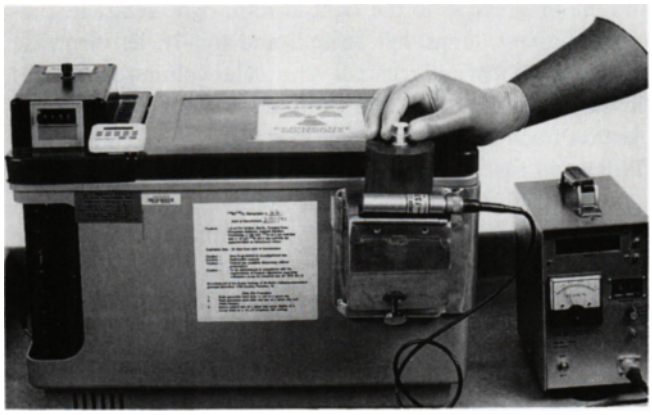

FIG. 5. The short half-life of tantalum-178 (9.3 min) makes it necessary to have a portable generator, which can be eluted at bedside.

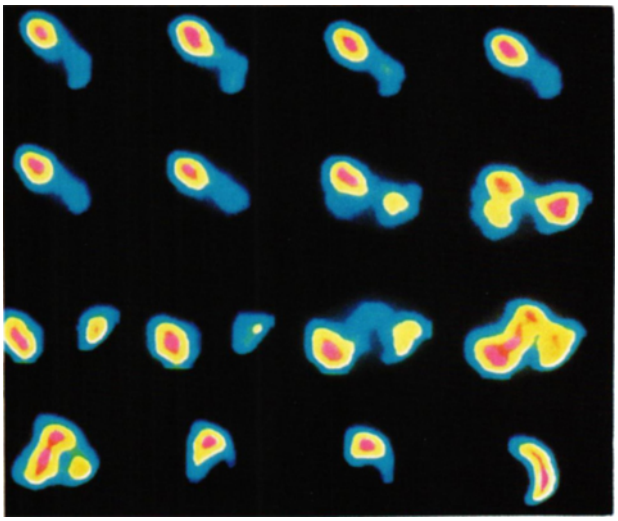

FIG. 6. First-pass transit of the bolus injection with tantalum-178.

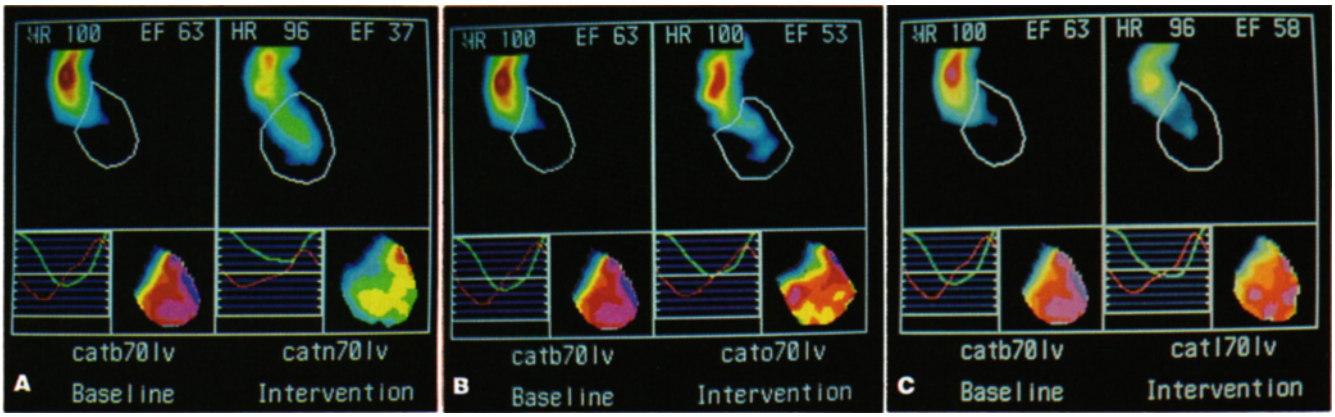

FIG. 7. Typical first-pass radionuclide angiograms as displayed for interpretation by multiwire gamma camera. Left ventricle is displayed in end-diastole (white ring) and end-systole (superimposed in blue). (A) At baseline, left ventricular function is normal with an ejection fraction of 63% (upper left) and normal regional function (lower left). Normal volume and flow curves are displayed on bottom left. During coronary occlusion (right) of the mid left anterior descending coronary artery, there is left ventricular dilation and diffuse hypokinesis. The ejection fraction fell to 37%. (B) During occlusion of the mid right coronary artery in same patient, there is anterior and apical hypokinesis. The ejection fraction was 53%. (C) During occlusion of the left circumflex coronary artery in same patient, only slight fall in ejection fraction occurs (58%).

shows the arrival of the tracer bolus in the vena cava (top left) and the progression to the right atrium, right ventricle, pulmonary artery, lungs, left atrium, and finally, left ventricle and aorta. Global and regional ventricular volume curves and flow curves are plotted, and from them, global and regional ejection fraction, peak ejection rate (PER), peak filling rate (PFR), and times to peak emptying and filling.

Ventricular volume and cardiac output indices are calculated by the area-length method. A cine image of the cardiac cycle, separately for the left ventricle and right ventricle, is displayed in motion on the camera screen, providing qualitative wall motion assessment. The regional TACs in six regions of the ventricle are displayed as well as a regional EF assessment image (REFI).

RESULTS

Data processing was completed on-site within ~8 min, including calculation of LV EF, PER, PFR, and time to PER and PFR. Regional ventricular volume curves allowed assessment of segmental ejection and filling indices. During coronary occlusion, a significant transient depression of LV function was seen: the LV EF fell from 52% ± 12% to 40% ± 14% ($p = 0.0001$) and the peak filling rate fell from 2.4 ± 0.8 to 2.0 ± 0.8 EDV/sec ($p = 0.0007$).

Typical LV FPRNA images are illustrated in Figure 7. The image on the left of each panel was obtained during baseline and shows a normal LV contraction and an EF of 63%. During occlusion of the mid left anterior descending artery, severe deterioration of LV function occurs (Fig. 7A). During occlusion of the mid right coronary artery in the same patient, only mild deterioration of LV function occurs (Fig. 7B). During occlusion of the left circumflex coronary artery, only minimal deterioration occurs (Fig. 7C).

CONCLUSION

The mobile MWGC, in association with generator-produced ^{178}Ta, allows us to study the changes in ventricular function during acute interventions in humans. The high level of injected doses, made possible by the short half-life of ^{178}Ta, coupled with the superior count-rate capability of the MWGC detector, produce high quality images. The highly automated software employed in this system enables bedside processing and interpretation of the studies. The data provide important physiologic information in a matter of a few minutes, with minimal discomfort to patients. The changes in ventricular function during transient occlusion of each of the proximal coronary branches have been reported in detail previously (*4*). This new technology allows wider use of FPRNA in critically ill patients, since these studies can now be performed at the bedside anywhere in the hospital.

ACKNOWLEDGMENT

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