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Publication Date

1975-12-01

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LBL-4633

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CEREBRAL IMAGING USING ⁶⁸GA DTPA AND THE U.C.S.F. MULTIWIRE PROPORTIONAL CHAMBER POSITRON CAMERA

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Abstract

A multiwire proportional chamber positron camera consisting of four 48 x 48 cm² detectors linked to a small digital computer has been designed, constructed, and characterized. Initial clinical application to brain imaging using ⁶⁸Ga DTPA in 10 patients with brain tumors is described. Tomographic image reconstruction is accomplished by an algorithm determining the intersection of the annihilation photon paths in planes of interest. Final image processing utilizes uniformity correction, simple thresholding, and smoothing.

The positron brain images were compared to conventional scintillation brain scans and x-ray computerized axial tomograms (CAT) in each case. The positron studies have shown significant mitigation of confusing superficial activity resulting from craniotomy in comparison to conventional brain scans. Central necrosis of lesions observed in the positron images, but not in the conventional scans, has been confirmed in CAT. Modifications of the camera are being implemented to improve image quality, and these changes combined with the tomography inherent in the positron scans are anticipated to result in images superior in information content to conventional brain scans.

Introduction

Although conventional brain scans are highly sensitive and specific, diagnostically, for etiologically diverse brain lesions, even more accurate modalities are being sought. Mathematically reconstructed sectional images based upon x-ray transmission data, computerized axial tomography (CAT) (1), or the opposed photons resulting from positron-electron annihilation (2) are examples of such new approaches, the former already having had significant clinical impact.

Positron cameras using dual position sensitive detectors have been available for some time, but have had limited clinical utility because of their expense, data rate limitations, or both (3,4). We have recently designed and fabricated a positron camera based upon multiwire proportional chamber (MWPC) gas filled detectors, using delay line event localization and honeycomb lead converters (5,6). Initial clinical application to cerebral imaging in patients with known brain lesions follows.

Methods and Materials

1. Camera

The camera consists of two opposed pairs of large-area detectors separated by approximately 50 cm operating in coincidence mode, the imaging subject being placed between them (Figure 1). Each detector is a MWPC with 48 x 48 cm² sensitive area coupled to honeycomb converters in proximity to the chamber-wire planes

(Figure 2). Each coupled pair of MWPC's is operated in an anti-coincidence mode in order to suppress multiple interactions and cosmic ray background, and pile-up rejection circuitry is used to eliminate events occurring within the dead time of a MWPC. Derandomizing data registers are used in the interface electronics to decrease data transfer dead-time. The position localization of the incoming 511 keV annihilation photons is effected by their interaction with the converters and subsequent coordinate detection of the ionization produced by conversion electrons. A small computer is used for data acquisition, processing and display.

An effect of the honeycomb converters is that the spatial resolution is improved by limiting the range of most conversion electrons to the cell size. However, because of the varying distance from the cathode to the cell depth where ionization occurs, differing drift time results, degrading time resolution. The use of converters also voids the possibility of pulse-height analysis, which is not a severe drawback as will be shown below.

Initial camera performance has been reported recently (Table 1). The positron camera shows a spatial resolution of 6-7mm FWHM on the image plane and a resolving time of 300-nanoseconds full width. Because of its large solid angle coverage adequate detection efficiency is achieved, of the order of 675 counts/min- μ Ci with a maximum useful data rate of 18K counts/min.

TABLE 1
TECHNICAL SURVEY RESULTS

Sensitivity	675 counts/min- μ Ci
Detector Sensitive Area	48 x 48 cm ²
Angular Acceptance	$\pm$ 45-degrees
Maximum Useful Data Rate	300/sec
Spatial Resolution	6 mm FWHM in air, 7 mm FWHM in 10 cm lucite
Energy Resolution	None
Time Resolution	300 nsec full width

The effects of scattering material in the path of the annihilation photons have been investigated. While the total count rate drops exponentially as expected, the rate of on-target to total count rate drops more gradually. Tests with Cu-64 line sources ($E_{\beta^+} = 656$ keV) imbedded in 1.25 cm and 10 cm of lucite have shown spatial resolution of 6 mm and 7 mm FWHM, respectively, with a slight increase of background level in the latter case. Thus, scattering has a relatively small effect on both the signal-to-background ratio and spatial resolution, and the lack of energy resolution in the MWPC's case does not signifi-

cantly alter the performance of the system.

There is an important advantage to the fact that detection efficiency for an event is the same over a large range of photon energies in lead converter based MWPC detectors (150 keV to 1 MeV). In NaI the detection efficiency drops as energy increases; thus relatively increasing the detection of Compton-scattered photons. This is why lead filters have proven advantages for improving NaI-based positron cameras, which operate without pulse-height selection. Thus, the characteristics of the MWPC detectors reproduce those of lead-filtered NaI detectors without the loss of efficiency associated with the lead.

Phantom studies have been accomplished with a simple hollow head phantom, showing easy detection of lesions with concentration ratios as low as 5:1 over background (Figure 3).

2. Radiopharmaceutical

^{68}Ga is obtained by 0.03M EDTA elution from ^{68}Ga complexed to a cation exchange resin in a column. The eluted ^{68}Ga is complexed to 0.1M DTPA (Diethylene triamine penta-acetic acid) in 0.9% saline by incubating at 60°C. for 10 min. The radiopharmaceutical migrates as a single peak on paper chromatography, and is sieved by 0.2 μ millipore filtration prior to intravenous administration. ^{68}Ga DTPA was chosen on the basis of the excellent properties of $^{99\text{m}}\text{Tc}$ DTPA for brain imaging (7). Data is collected for approximately 30 min., 1-1/2 to 2-1/2 hours after administration of 1-2 mCi of the agent. Based upon the distribution kinetics of $^{99\text{m}}\text{Tc}$ DTPA radiation doses of 5.5R/mCi, 1R/mCi, and 0.05R/mCi are calculated for bladder, kidneys, and whole body respectively, using the absorbed dose fraction method(8). These values are about half those incurred during conventional brain scintigraphy using a typical injection dose of 15 mCi $^{99\text{m}}\text{Tc}$.

3. Imaging Technique

The patient is positioned such that his head is midway between the detectors resting on a pillow with the sagittal plane perpendicular to the detectors. 100-200K coincidence events are accumulated over approximately 30 minutes.

4. Image Reconstruction

Image reconstruction is performed off-line. A series of tomographic images in frontal projections are generated at 1-2 cm intervals and displayed in a 64 x 64 element array. Images are formed by calculating the intersection of the detected annihilation vectors with the selected focal plane and by displaying them in a 64 x 64 matrix on the storage CRT after field uniformity correction. Because of the large solid angle coverage of the camera, digital displacement of a reconstruction plane by even 1 cm shows a significant change, since the effect of point sources on the off-focal plane diminishes rapidly. After thresholding and a single center weighted smoothing, images are photographed with Polaroid off the PDP 11's storage oscilloscope.

5. Corroborative Documentation

X-ray computerized axial tomography (CAT) is obtained using the EMI scanner, in eight 1 cm transverse sections, with and without iodinated contrast infusion (meglumine iohalamate). Conventional brain scans are obtained in multiple projections using a 37 phototube scintillation camera 1 to 2 hours after the administration of $^{99\text{m}}\text{Tc}$ DTPA.

6. Patients

Ten patients with known brain lesions were studied after obtaining informed consent. The lesions were primary malignant brain neoplasms in the majority, with one brain abscess and one metastatic lesion from a bronchogenic adenocarcinoma.

Results

In eight of the ten positron brain studies the lesions were easily identified. In one of the two remaining patients (the first studied) the images were technically unsatisfactory due to substandard performance of the camera, and in the second the lesion was poorly seen. Five representative studies with corresponding conventional brain scintigraphs, and CAT are shown in Figures 4-8. The superb tomography is evident by the discretely focused image planes. Positron images significantly mitigate superficially increased activity secondary to craniotomy, leading to failure of the conventional scan to definitely show an intracranial focus, when one is present. Central necrosis of lesions corroborated in CAT is seen in the positron images, when not evident in conventional scans. Lesion extent appeared occasionally underestimated in conventional scans compared to the positron images and CAT.

Discussion

The MWPC positron camera potentially offers a number of advantages over the other systems. Some of these are: 1) low system cost; 2) low cost, large sensitive area detectors; 3) good efficiency for static imaging; 4) good spatial resolution; 5) good uniformity response; and 6) excellent tomography permitted by the broad solid angle of large detectors. In this patient series the positron images, although crude, often provided more information than the conventional brain scans (see Figures 4,5,6).

Overall evaluation of diagnostic performance of the system, including patient factors suggest additional benefits. The ^{68}Ga is the 1.13 hr. $T_{1/2}$ daughter of ^{68}Ge , $T_{1/2} = 275$ d. The chemistry allows fabrication of a generator system, elutable every two hours, requiring replacement every 1.5 - 2 years. Delivery logistics and economic considerations of such a system permit very wide spread availability of the radiopharmaceutical. The low injected dose (1-2 mCi) required and the short $T_{1/2}$ result in a 50% reduction in radiation exposure compared to a conventional brain scan using 10-15 mCi $^{99\text{m}}\text{Tc}$. A data set is accumulated from a single positioning of the patient, saving repositioning time. Planned system upgrading is anticipated to result in improved sensitivity and spatial resolution, the former to a degree permitting image deconvolution to subtract the influence of off axis planes.

Acknowledgements

Dr. R.S. Hattner is a Picker Scholar, James Picker Foundation. This work was supported by the RANN division of the National Science Foundation.

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FIGURE CAPTIONS

Figure 1. MWPC Positron Camera: (Left) Detection System, (Center) CAMAC coordinate processing electronics, (Right) PDP 11/20 computer.

Figure 2. Schematic of MWPC-Converter Detector Construction: (Top) The sectional side view shows the relative positions of the lead converters to the chamber wire planes. (Bottom) The anode and cathode wire chamber planes are coupled to the X and Y delay lines for localization of conversion electrons.

Figure 3. Head Phantom With $30\mu\text{Ci } ^{68}\text{Ga}$: (Left) Lesion to background ratio of 10:1; (Right) Two lesions, one 5:1, and one 0:1.

Figure 4. Right parietal oligodendroglioma. Note central necrosis evident in the 5.0 cm plane, not apparent in conventional scan, lower left, but confirmed in CAT, lower right.

Figure 5. Right parietal glioma. In conventional scan (Lower Left two images) lesion is obscured by superficial activity due to craniotomy. True intracranial extent is evident in positron images and CAT (Lower Right).

Figure 6. Bronchogenic carcinoma metastatic to left cerebellar hemisphere. Lesion comes into focus in 4 cm plane and persists to 8 cm plane. Conventional scan (Lower Left two images) shows same lesion; CAT is of poor diagnostic quality because of movement artifact, but suggests the lesion.

Figure 7. Extensive corpus callosum glioma with midline extension. The degree of extension into the left hemisphere suggested in CAT (Lower Right) is much more evident in the positron scan, than the conventional scan (Lower Left two images).

Figure 8. Superficial right parietooccipital glioblastoma multiforme. Lesion in sharp focus at 4 cm. Note superb tomography with lesion fading in 6 cm plane. Lesion less well seen in conventional scan (Lower Left two images), and barely suggested in CAT (Lower Right).

Fig. 1

CBB 745-3643

Fig. 2

XBL 739-1173

XBB 756-4148

Figure 3

XBB 7511-8473

XBB 7511-8470

XBB 7511-8472

XBB 7511-8471

Fig. 8

XBB 7511-8468

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