Brain Perfusion SPECT Using an Annular Single Crystal Camera: Initial Clinical Experience

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The annular single-crystal brain camera (ASPECT) is a digital SPECT system with a single-crystal sodium iodide thallium NaI(Tl) ring detector and collimator system designed to view the patient's head from three angles simultaneously. The ring is rotated concentrically to the detector for three-dimensional reconstruction over a 21.4 cm (diameter) by 10.7 cm (length) field of view. We evaluated the system clinically by imaging a Hoffman brain phantom and seven subjects, of whom two were normal controls, three had previous cerebral infarction and two had dementia. The ASPECT system produced tomographic images of high spatial resolution. In normal subjects, the separation of striata from thalami by the posterior limbs of the internal capsules was much clearer on ASPECT images than on rotating gamma camera images. The high spatial resolution obtained with the ASPECT system translates into superior anatomical representation of the brain compared to the standard rotating gamma camera.

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The development of iodine-123- and technetium-99m-labeled radiopharmaceuticals with biodistributions that reflect regional cerebral blood flow (rCBF) has revived interest in brain scintigraphy (*1–4*). Perfusion SPECT has been found to be clinically useful in a wide range of neurologic diseases, including stroke, dementia, epilepsy and trauma (*5–8*). SPECT instrumentation has lagged behind radiopharmaceutical development, however. Most studies are currently performed using the rotating gamma camera, a versatile instrument with poor sensitivity and tomographic spatial resolution. Despite the heavy reliance on the single-headed Anger camera, several avenues have been followed in an effort to increase sensitivity: 1) the multiheaded camera integrates two or more Anger cameras into one instrument, increasing the cost but also increasing sensitivity because of the greater detector surface area; and 2) dedicated multi-detector ring-type brain systems result in high sensitivity because crystal surface area and detector thickness is increased. Each of the specially designed systems currently in clinical use have limitations including either high cost, poor z-axis resolution, or single or discontinuous slice acquisition and all of them fall short of the goal, a continuous 360-degree ring of detector surface encircling the brain.

Genna and Smith have recently described an annular single-photon emission tomography system (ASPECT) designed for three-dimensional brain imaging (*9–10*). The system uses a stationary annular single crystal position sensitive detector and a three-section rotating collimator. We report the initial clinical experience using the ASPECT imaging system and the brain perfusion tracer, ^{99m}Tc-HMPAO (Ceretec, Amersham Ltd, Amersham, UK).

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METHODS

The detector of the ASPECT brain imager consists of a stationary annular crystal of sodium iodide having an inside diameter of 31 cm and a thickness of 8 mm. An annular collimator system, comprised of three parallel-hole collimators of equal size concentric to the crystal, is rotated imcrementally so as to collect image data from gamma rays projected onto the inner surface of the crystal (Fig. 1). Scintillations are detected by an azimuthal/axial array of 63 photomultipliers arranged in three rings evenly distributed on the outer surface of a 12.5 mm thick pyrex window and integrally bound to the sodium iodide scintillator. Each photomultiplier output is digitized and the positioning algorithm, including linearity and energy corrections, is implemented digitally using dedicated hardware and an array processor.

Each of the collimator sections has hexagonal hole openings of 1 mm, a length of 2.4 cm and a septal thickness of 0.18 mm. The measured system resolution in air using capillary line sources is 8.2 mm at the center and 7.3 mm at 9 cm from the center for ^{99m}Tc. The sensitivity in air is 7.5 cps/μCi for a point source at the center and is uniform throughout the 21.4 cm diameter by 10.7 cm axial field of view (Table 1).

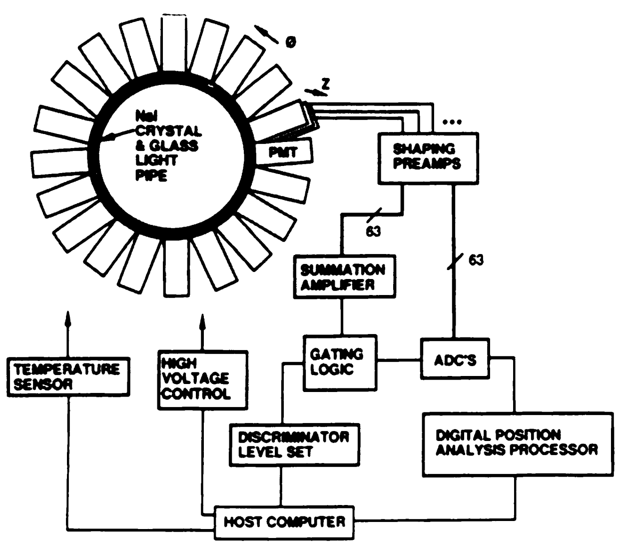

FIGURE 1
A block diagram of the annular single crystal scintillation camera (ASPECT). The 63 signals from the photomultipliers (PMT) are conditioned by the 63 preamplifiers and are then digitized in the 63 analogue-to-digital converters (ADCs). A gating signal is derived from the sum of all 63 preamplifier outputs. The digital signal processor (array processor) and the host computer control all aspects of crystal corrections, collimator/crystal sensitivity normalization, data collection and data processing.

All data on the ASPECT were acquired with an acquisition time of 15 sec per projection (a total acquisition time of 30 min), in 120 projections with a 360-degree rotation of the collimators. Two pulse-height analyzer windows were employed, one set at 140 ± 14 keV and one set to acquire scatter information from 112 to 126 keV. These two data sets were stored in separate arrays under the control of a personal computer running the MS-DOS operating system. After the completion of acquisition, the collimator/crystal normalizations were performed on each data set. A combined set of projections were then calculated by subtracting 90% of the scatter projections filtered to remove the forward scatter component, from the photopeak projections. The projections were prefiltered using a Butterworth filter (cutoff = 0.175 cycles per pixel; power factor = 20). The reconstructed slices were attenuation corrected and displayed on a 128 × 128 matrix (1.67 × 1.67 mm) as a set of 64 slices (1.67 mm slice thickness). Coronal, saggital, and rotating three-dimensional displays were calculated from these slices.

TABLE 1
Comparison of Performance for ^{99m}Tc between ASPECT and GE 400 ACT with Long-Bore and Low-Energy All-Purpose (LEAP) Collimators

	ASPECT (11)	GE 400 ACT (12)	
		Long-bore	LEAP
Tomographic spatial resolution (FWHM (mm))	8.2	17	23
Volume sensitivity* (cps/μCi/cc/axial cm)	1000	270	790
Point source sensitivity (cps/μCi)	7.0	1.8	5.3

* Measured with 20 cm diameter cylindrical phantom.

Imaging characteristics of a rotating gamma camera (General Electric 400 ACT, General Electric Corporation, Milwaukee, WI) and ASPECT were compared. A Hoffman brain phantom (Data Spectrum Corporation, Chapel Hill, NC) was filled with a uniform stock solution of [^{99m}Tc] pertechnetate with a specific activity of 6 μCi/ml. The phantom solution specific activity was chosen to reflect the photon flux expected in routine clinical brain perfusion SPECT with ^{99m}Tc-HMPAO. The phantom was placed horizontally on the collimator of the rotating gamma camera. A planar scintigraphic image was obtained using a 128 × 128 matrix (300K counts) to check for adequate mixing. Following acquisition of the planar image, the phantom was placed vertically in a clinical head holder attached to the imaging table. A long-bore collimator, whose characteristics were previously described (*12*), was used for all tomographic acquisitions and collection parameters were selected to represent a standard clinical study. Data were acquired with a 64 × 64 matrix, sampling 64 projections in a 360-degree circular arc with 30-sec data collections per projection (a total acquisition time of 30 min). All projection data were corrected retrospectively for uniformity variations with an extrinsic correction flood of 60 million counts. Projection data were reconstructed with a Ramp filter and corrected for attenuation using the Sorenson technique with an attenuation coefficient of 0.07. Projection data were prefiltered with a Butterworth filter (0.30 cycles per cm, power factor = 30) and reconstructed with a Ramp filter. The transaxial images were displayed on a 64 × 64 display matrix. The phantom was then placed vertically in the gantry of the ASPECT brain imaging system and a tomographic data set was acquired and processed as described in the preceeding paragraph.

Brain perfusion SPECT was performed in seven human subjects following the i.v. injection of 20 mCi of ^{99m}Tc-HMPAO using both the rotating gamma camera and ASPECT. Two of the subjects were asymptomatic controls with normal neurologic examinations and no evidence of disease involving the central nervous or cardiovascular systems. Three of the subjects had cerebral infarction, one patient had clinical evidence of Alzheimer's disease and one patient had diffuse atrophy with ventricular enlargement. Three subjects were studied first with the rotating gamma camera and four with ASPECT. Acquisition and processing parameters were as described above for the rotating gamma camera and for ASPECT. Imaging time was increased for the second study to compensate for radioactive decay.

RESULTS

The ASPECT system produced Hoffman brain phantom images with significantly improved spatial resolution compared with images from the rotating gamma camera (Fig. 2). There was substantially better separation of deep structures that correspond to basal ganglia, thalamus and midline structures. Phantom cortical gyral structure was also better resolved with ASPECT

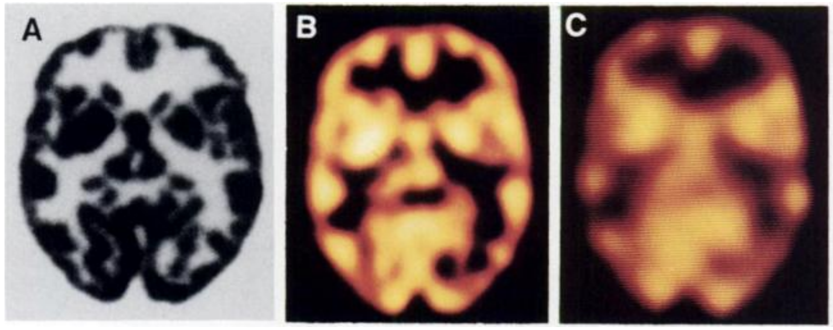

FIGURE 2
(A) High resolution planar images of the Hoffmann brain phantom, (B) ^{99m}Tc SPECT of the phantom with ASPECT, and (C) with a single detector rotating gamma camera.

than with the rotating gamma camera, and was especially evident in the parietooccipital and frontotemporal boundaries.

In two normal subjects, brain structures were better resolved with ASPECT than with the rotating gamma camera (Fig. 3). In particular, the separation of striata (caudate and putamen) from thalami by the posterior limbs of the internal capsules was much clearer in ASPECT images, and even the separation of caudate and putamen was seen in lower ASPECT slices. The gyral architecture of the cortical ribbon was better seen with ASPECT than with the rotating gamma camera

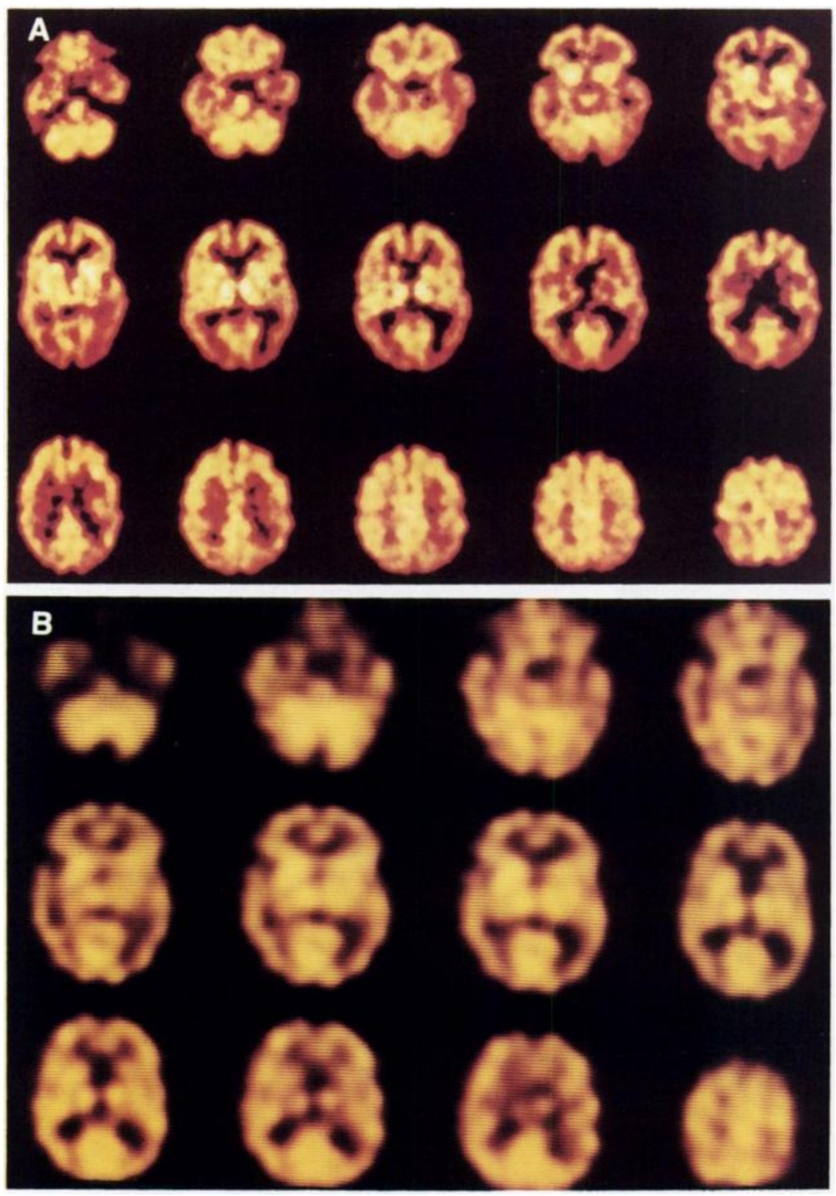

FIGURE 3
Transaxial ^{99m}Tc-HMPAO SPECT of normal subject with (A) ASPECT and (B) a rotating gamma camera.

system. Thus, there was improved separation of activity within the highly convoluted occipital and peri-Sylvian cortexes. Moreover, apparent discontinuities in the cortical mantle suggested by the rotating gamma camera images in the temporal tips and parietooccipital junctions were more precisely displayed with ASPECT as regions of lower perfusion.

Three subjects had clinical histories of stroke with onset of neurologic symptoms and signs less than seven days prior to SPECT (Table 2). One, a 52-yr-old woman, had acute onset of left hemiparesis and developed MR evidence of infarction involving the right putamen and internal capsule with extension into the centrum semiovale. There were other lesions, thought to represent chronic infarction, involving the head of the right caudate nucleus, the left posterior limb of the internal capsule and the left temporal cortex. Perfusion defects on ASPECT corresponded very well with the MR abnormalities, but rotating gamma camera SPECT images did not discriminate the several abnormalities in the right basal ganglia and showed only an equivocal abnormality on the left side (Fig. 4). Two other patients each had large middle cerebral artery territory infarction detected with both ASPECT and rotating gamma camera SPECT. The extent of the perfusion defects appeared similar with both modalities (Fig. 5). A fourth patient with diffuse brain shrinkage and ventricular enlargement had diffusely reduced cortical uptake of ^{99m}Tc-HMPAO on both modalities. The last patient, a 72-yr-old male with memory loss and clinical evidence of Alzheimer's disease, had markedly reduced perfusion to the parietal and posterior temporal lobes bilaterally but more severely on the left. The perfusion defects were extensive and severe and clearly evident on both rotating gamma camera SPECT and ASPECT.

DISCUSSION

We describe initial clinical results obtained with an annular brain imaging system that uses a solid sodium iodide detector encompassing the entire brain within the field of view. The system is well suited for brain imaging because its annular crystal and collimator permit uniform axial sampling with spatial resolution identical to the in-slice resolution. This isotropic sampling and resolution permits true three dimensional reconstruction of the brain and facilitates comparison to other three-dimensional modalities such as MRI and CT.

In order to compare ^{99m}Tc-HMPAO images obtained with ASPECT with image obtained using the rotating gamma camera, we studied a group of subjects with stroke or dementia and normal subjects. We found a significant improvement in spatial resolution of the cortical and deep brain structures using the annular (ASPECT) system. The high spatial resolution obtained with the ASPECT system translates into superior anatomic representation of the brain compared to the standard rotating gamma camera. Whether this will improve diagnostic accuracy in specific disease states is unknown. However, we demonstrate the value of ASPECT images in patients with small perfusion defects below the resolution of standard Anger camera tomography. In a patient with recent stroke and several presumed infarcts involving different regions of the basal ganglia and cortex, the size and number of these small

TABLE 2
Demographic, Clinical, and Radiologic Data on Seven Subjects Studied

Patient no.	Age	Sex	MRI/CT	Brain SPECT* (Tc-99m-HMPAO)	Diagnosis
1	72	M	Normal	Normal	Normal
2	21	F	Normal	Normal	Normal
3	38	M	Proximal L posterior temporal artery embolus (angiography)	L temporal lobe perfusion defect	Embolic CVA
4	52	F	R basal ganglia and left temporal infarcts	R basal ganglia and L temporal perfusion defects (ASPECT only)	Vasculitis with multiple infarcts
5	35	M	Large left-sided infarction involving the basal ganglia and internal capsule	Diffusely decreased perfusion of the L hemisphere	Embolic CVA
6	61	M	Diffuse cerebral atrophy	Diffusely decreased cerebral pefusion	Dementia
7	72	M	Normal	Decreased perfusion to posterior temporoparietal regions, bilaterally	Dementia (AD type)

* Brain SPECT results in both systems; CVA = cerebrovascular; AD = Alzheimer's disease.

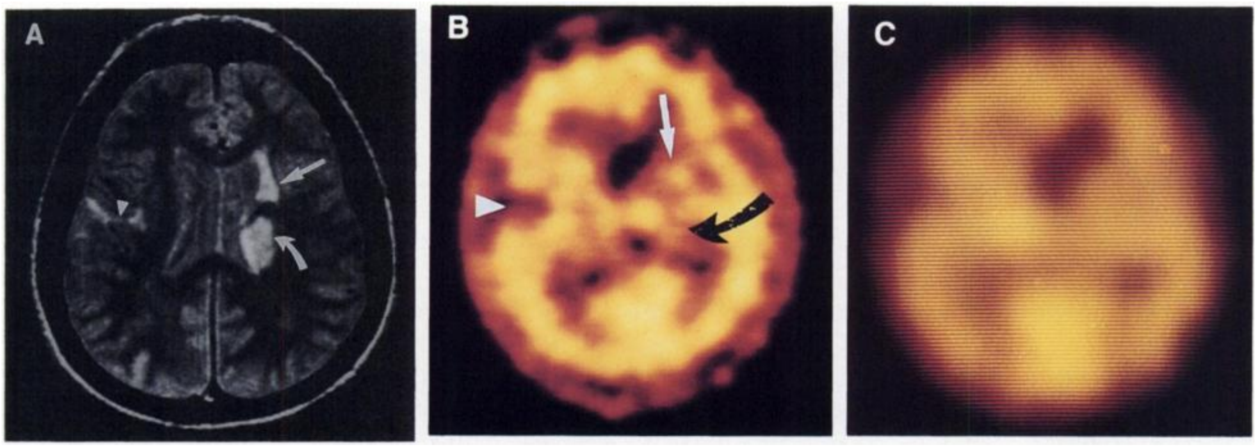

FIGURE 4
(A) Transaxial MR in a patient with multiple small cerebral infarcts involving the head of the caudate (arrow) and putamen (curved arrow) on the right and anterior temporal lobe (arrow head) on the left, (B) ^{99m}Tc-HMPAO SPECT in the same patient using ASPECT and showing focal areas of decreased uptake involving the head of the caudate (arrow) and the putamen (curved arrow) on the right and the temporal lobe on the left (arrow head) in the same locations as on MRI, and (C) ^{99m}Tc-HMPAO SPECT at the same transaxial level with a rotating gamma camera. The areas of decreased uptake are faintly seen and were not appreciated on initial interpretation.

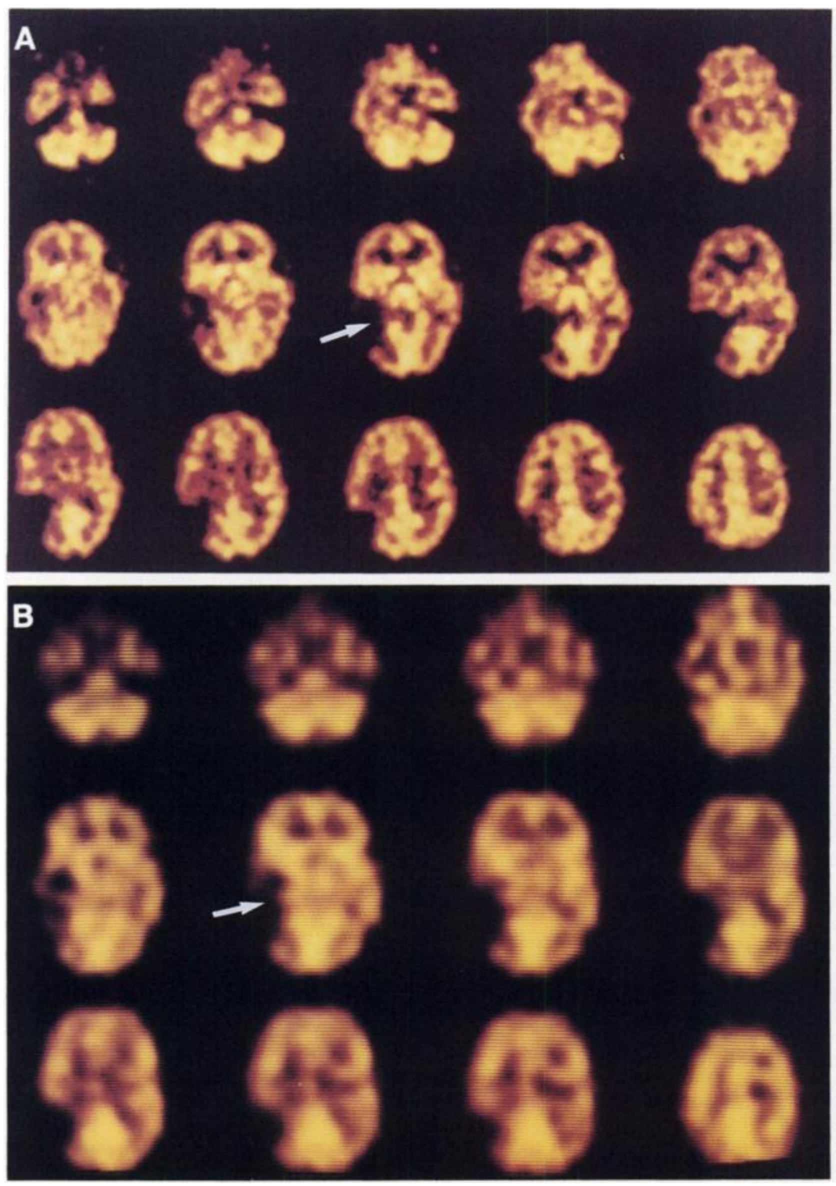

FIGURE 5
Large left middle cerebral artery infarct involving its posterior branches seen well on both (1) ASPECT (arrow) and (B) rotating gamma camera transaxial SPECT (arrow).

lesions was clearly defined with ASPECT while the rotating gamma camera failed both to reflect the severity of the perfusion defects and to define their anatomic boundaries. We found that large defects or diffuse perfusion abnormalities, as are often seen in stroke or dementia, were detectable with either SPECT system, but these diseases are very frequently characterized by perfusion abnormalities coexisting in both large and small brain regions. Instances of major neurologic deficits arising from small lesions are well known (*13*).

As the use of brain perfusion SPECT moves from initial screening of stroke and dementia toward the assessment of neurologic abnormalities with smaller anatomic substrates, high-resolution SPECT systems will be better suited to image changes in brain functional activity. In particular, higher resolution will aid the development of activation strategies designed to stress smaller brain regions thought to subserve specific cognitive or sensorimotor functions that are frequently found to be impaired in clinical practice.

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