Brain SPECT Using a Dedicated Three-Headed Camera System

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The clinical efficacy of a brain-dedicated single-photon emission tomography (SPECT) system, (GE/CGR Neurocam, GE/CGR, Buc, France) was assessed in normals and in a variety of brain disorders. Its three Anger-type gamma camera heads form a triangular aperture and offer a substantial increase in sensitivity compared to a single rotating camera. This has allowed the routine use of high resolution collimators for technetium-99m hexamethyl propylene amine oxime brain SPECT studies. The resulting improvement in spatial resolution, coupled with ease of patient positioning and greater patient throughput (compared to a conventional tomographic gamma camera) will enhance the role of brain SPECT for both routine and research purposes. The Neurocam is also suitable for dynamic SPECT studies with iodine-123 iodobenzamide.

The introduction of multi-headed gamma camera systems for single-photon emission computed tomography (SPECT) has resulted in a significant increase in sensitivity compared to a single rotating gamma camera (*1–4*). This has led to exciting possibilities for optimizing the acquisition protocols according to which SPECT procedures are performed. The pertinent parameters are: amount of administered activity, collimator choice, and total data acquisition time. With such an increase in sensitivity, it is now possible to either decrease the administered activity or acquisition time, or to reach a compromise with both. Coupled with use of high resolution (HR) collimators, this can yield improved image quality.

In this paper, we report our experience with a new brain-dedicated three-headed system, the GE/CGR Neurocam. First, we describe this system and the protocols that we have used in a variety of brain tomographic studies. Then we provide examples of a normal volunteer and selected patients, thereby demonstrating the clinical efficacy of this instrument as a multi-slice brain imager for both routine and research studies.

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MATERIALS AND METHODS

The Neurocam is comprised of three Anger-type gamma camera heads fixed in a rotating gantry (*5*). The front faces of the heads form an almost equilateral triangular aperture. Each head has 27 photomultiplier tubes (PMTs), coupled to a 6.5-mm thick sodium iodide crystal with adequate shielding for gamma-ray energy up to 170 keV. The field of view is 20 cm × 17.6 cm. Patient positioning is easy, fast, and reproducible. The patient's head fits within the triangular aperture. The height of the headrest is fixed with respect to the gantry. The imaging table locks into place when pushed into the aperture. Collimators are light and easily handled. Data acquisition is controlled by an IBM-compatible personal computer. Energy correction is performed on-line; linearity and uniformity corrections are made off-line for each planar image. Further processing, including center of rotation (COR) corrections, is performed on a GE Star computer (GE Star 3000 computer, GE Medical Systems, Milwaukee, Wisconsin) after data transfer.

The tomographic volume sensitivity of the Neurocam was measured for both the HR and the general purpose (GP) parallel-hole collimators and was compared to that of a single-headed camera (GE 400XCT computer, GE Medical Systems, Milwaukee, Wisconsin). A water-filled cylinder (20-cm diameter × 30 cm) containing technetium-99m (^{99m}Tc) pertechnate was used; the count rate was <20,000 cps. The reconstructed spatial resolution was measured using ^{99m}Tc line sources both in air and in a water-filled cylinder (*6*). The data acquisition parameters were: 128 projections, 128 × 128 matrix, corresponding to a pixel size of 2 mm; reconstructions were performed using the ramp filter.

Capitalizing on the increased sensitivity, we used the HR collimators for most of our brain perfusion studies with ^{99m}Tc-hexamethyl propylene amine oxime (HMPAO). For these studies, the GP collimators were used only for restless patients (e.g., patients with infantile autism) for whom acquisition with a single rotating gamma camera would probably not be possible. However, the GP collimators were used for the iodine-123 iodobenzamide ([^{123}I]IBZM) studies because of the lower count rate and the requirement to perform dynamic SPECT. The GP collimators were also used for the ^{201}Tl-chloride studies.

To date we have imaged more than 300 subjects, some of them more than once, using either different acquisition parameters after a single injection or the same acquisition parameters on separate occasions in order to follow the effects of therapy. Depending on the case under investigation, the data acquisition parameters were: 64 or 128 projections, 64 × 64 or 128 × 128 matrix, 5–40 sec per projection. Since at each step during the rotation, three projections are acquired simultaneously, the total acquisition time for a typical ^{99m}Tc-HMPAO study with 740 MBq for an adult, 128 projections, and 20 sec per projection takes about 14 min. The ^{99m}Tc-HMPAO data were acquired with a 20% energy window, shifted by 3% to the high energy side. The [^{123}I]IBZM and ^{201}Tl-chloride data were acquired with a 20% symmetric window.

Tomographic reconstruction of patient data was performed using the filtered backprojection method. The projection data were prefiltered using the Hanning filter with cut-off frequency in the range 0.8–1.2 cycles/cm, depending on the total number of counts (higher for more counts). Backprojection was done using the ramp filter and the attenuation correction procedure assumed a uniform linear attenuation coefficient of 0.12 cm^{-1}.

RESULTS

The full physical assessment of the Neurocam will be reported elsewhere. Briefly, the tomographic volume sensitivity is 30 and 50.7 kcps/MBq/ml/cm for the HR and GP collimators, respectively. For comparison, the sensitivity of the single-headed GE 400XCT camera with GP collimator is 12.8 kcps/MBq/ml/cm. With the HR collimators, the tomographic resolution in water at the center of the field of view is 9.7 mm at full width at half maximum and 17.5 mm at FWTM. The corresponding values in air are 9 and 15.9 mm for the HR collimators (10.7 and 18.9 mm for the GP collimators).

Table 1 lists typical SPECT imaging protocols used at our institution for brain perfusion studies with ^{99m}Tc-HMPAO, using HR collimators. The acquisition parameters and resulting total acquisition time, counts per projection, and total counts are compared with those for a single rotating gamma camera (GE 400XCT). It can be seen that although the total acquisition time with the Neurocam is reduced to one third of that needed by a single rotating gamma camera, the total counts are increased by about 50%.

TABLE 1. Comparison of GE/CGR Neurocam and GE 400XCT Acquisition Protocols, Time, and Counts for ^{99m}Tc-HMPAO SPECT

Parameter	GE/CGR Neurocam	GE 400XCT
Collimators	HR	HR
No. of views	128	64
Matrix size	64	128
Pixel size (mm)	4.0	3.2
Energy window, shift	20%, 3%	20%, 3%
Time per view (sec)	20	30–40
Total time (min)	14	35–45
Counts per view (kct)*	35	50
Total counts (kct)*	4,480	3,200

* 740 MBq ^{99m}Tc-HMPAO administered activity for an adult.

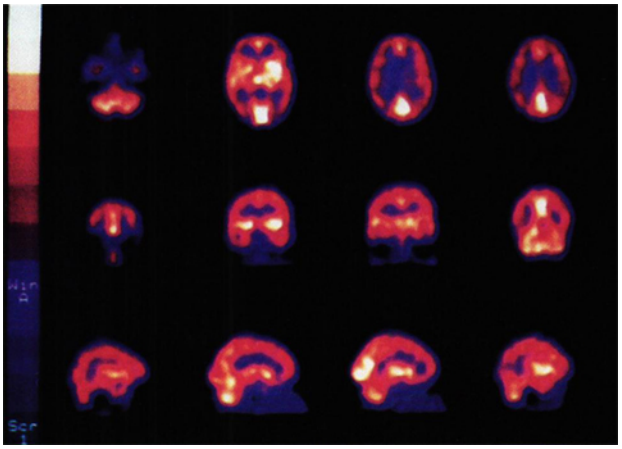

FIG. 1. Normal volunteer demonstrating normal HMPAO SPECT images.

Figures 1–7 present examples of tomographic images obtained with the Neurocam for a normal volunteer and six patients with a variety of brain disorders. The data acquisition protocol and brief findings for each case were as follows.

Case 1: Normal volunteer, 72-yr-old female. The acquisition parameters were: 726 MBq/kg ^{99m}Tc-HMPAO IV, GP collimators, 128 projections, 15 sec per projection (11 min total time), 64 × 64 matrix. Figure 1 shows normal HMPAO SPECT images: horizontal (parallel to OM-line), coronal, and saggital slices.

Case 2: Patient with multi-infarct dementia, 65-yr-old female. The acquisition parameters were: 710 MBq/kg ^{99m}Tc-HMPAO IV, HR collimators, 128 projections, 20 sec per projection (14 min total time), 64 × 64 matrix. Figure 2 shows horizontal (parallel to OM-line), coronal, and saggital slices demonstrating multiple wedge-shaped perfusion deficits in-

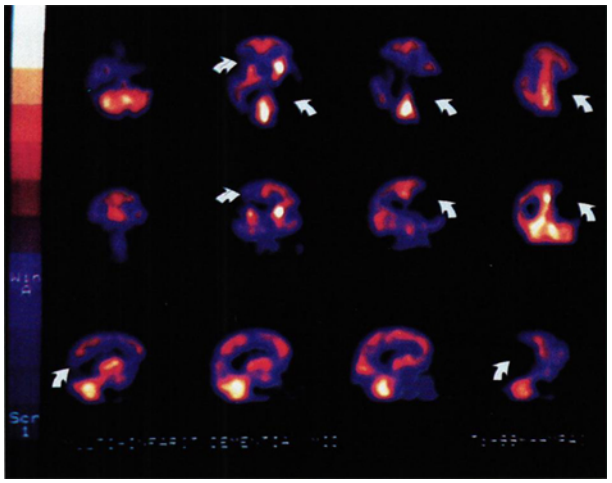

FIG. 2. Patient with multi-infarct dementia demonstrating multiple wedge-shaped perfusion deficits (arrows).

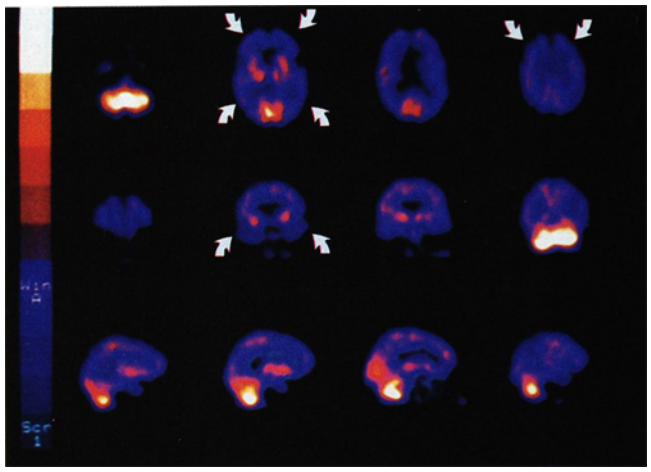

FIG. 3. Patient with Alzheimer's disease demonstrating bilateral symetrical perfusion deficits (arrows).

volving the right frontal and parietal lobes, and the left parietal and temporal lobes.

Case 3: Patient with dementia of the Alzheimer type, 74-yr-old male. The acquisition parameters were: 734 MBq/kg ^{99m}Tc-HMPAO IV, HR collimators, 128 projections, 20 sec per projection (14 min total time), 64 × 64 matrix. Figure 3 shows horizontal (parallel to OM-line), coronal, and saggital slices demonstrating bilateral symmetrical perfusion deficits in the frontal, parietal, and temporal lobes. Frontal atrophy and dilated ventricles are also noted.

Case 4: Patient with infantile autism, 25-yr-old male. The acquisition parameters were: 726 MBq/kg ^{99m}Tc-HMPAO IV, GP collimators, 128 projections, 15 sec per projection (11 min total time), 64 × 64 matrix. Figure 4 shows horizontal (parallel to OM-line), coronal, and saggital slices. A generalized reduction of brain perfusion was noted with more accentuated deficits in the frontal and temporal lobes.

Case 5: Patient (67-yr-old male) with a history of multiple transient ischemic attacks (TIAs) with right and left carotid artery stenosis assessed prior to endarterectomy. Two studies were performed sequentially: a cerebral blood volume (CBV) study with 780 MBq ^{99m}Tc-tagged red blood cells (RBCs) and a cerebral blood flow (CBF) study with 738 MBq/kg ^{99m}Tc-HMPAO. The acquisition parameters were: HR collimators, 128 projections, 30 sec per projection for the CBV study and 20 sec per projection for the CBF study, 64 × 64 matrix. Figure 5 shows horizontal (parallel to OM-line) CBV slices and corresponding CBF slices obtained by subtracting the first from the second study. The CBF/CBV images reflect perfusion reserve.

Case 6: Patient (56-yr-old male) with intracerebral metastases of carcinoma of the lungs. Two studies were performed sequentially. After the administration of 91 MBq of ^{201}Tl-chloride, 64 projections were acquired with GP collimators, 60 sec per projection (22 min total time), 64 × 64 matrix. The ^{201}Tl-chloride transaxial slices in Figure 6 show intracerebral hot spots. After changing to HR collimators, 740 MBq ^{99m}Tc-HMPAO were administered for a CBF study. The acquisition parameters were: 128 projections, 20 sec per projection (14 min total time), 64 × 64 matrix. The ^{99m}Tc-HMPAO transaxial slices in Figure 6 show larger perfusion deficits than the size of the metastases.

Case 7: Patient with Parkinson's disease, 42-yr-old male: A dynamic SPECT study was performed: Twelve sequential tomographic scans were acquired at 10 min intervals starting at 1 min postinjection of 185 MBq of [^{123}I]IBZM. The acquisition parameters were: GP collimators, 64 projections, 64 × 64 matrix, 15 sec per view, (i.e., 6 min total time per scan). The sequential images demonstrated the temporal changes of the distribution of [^{123}I]IBZM in the brain. Following the twelfth scan, i.e., at 2 hr postinjection, a further data-set was acquired under the same conditions except that the time per projection was 40 sec. Figure 7 shows the transaxial slices reconstructed from this data-set demonstrating the distribu-

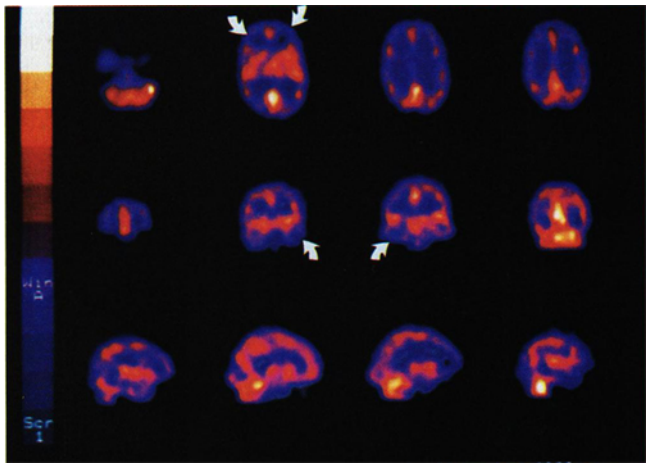

FIG. 4. Patient with infantile autism demonstrating accentuated deficits in the frontal and temporal lobes (arrows).

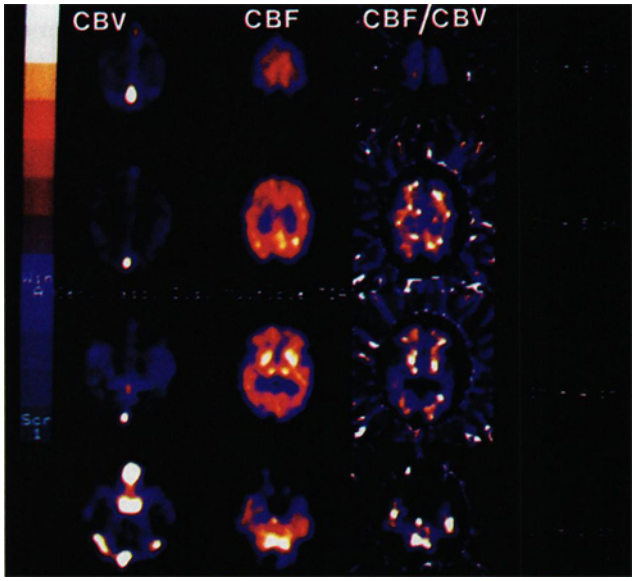

FIG. 5. Patient with a history of multiple transient ischemic attacks. CBF/CBV slices obtained by subtracting the CBV from the CBF study. The CBF/CBV images reflect perfusion reserve.

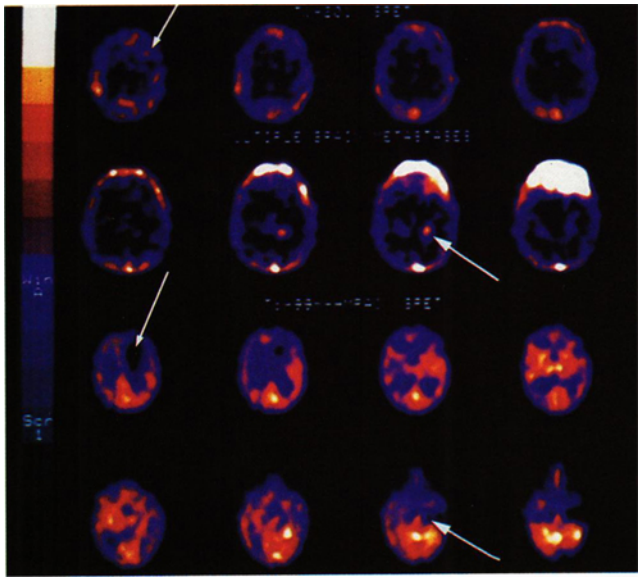

FIG. 6. Patient with intracerebral lung carcinoma metastases. Two studies were performed sequentially. Top two rows: ^{201}Tl-chloride study shows intracerebral hot spots. Bottom two rows: ^{99m}Tc-HMPAO study shows perfusion deficits.

tion and localization of IBZM in the brain. Significant tracer uptake is seen in the basal ganglia (head of caudate nucleus and putamen) of both hemispheres and low uptake in the cerebellum.

DISCUSSION

Multi-headed systems offer a substantial increase in sensitivity compared to a single gamma camera. The increased sensitivity may be exploited for increased patient throughput or better resolution. There are several commercially available three-headed systems, a four-headed system (*7*), an annular single-crystal camera (*8,9*), and other multiple discrete-detector systems.

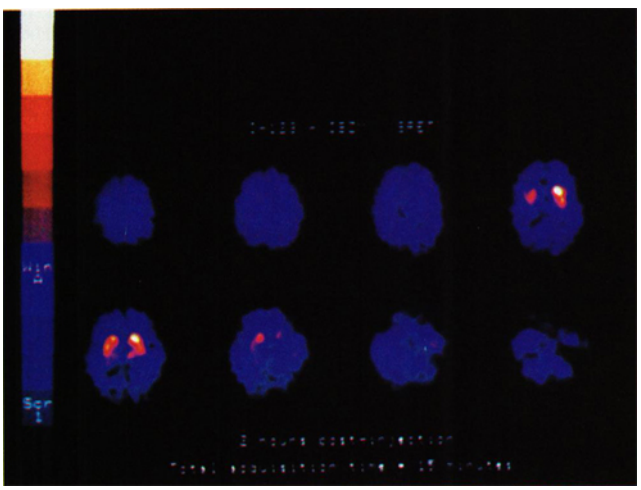

FIG. 7. Patient with Parkinson's disease. A dynamic SPECT dataset demonstrates the temporal changes of the distribution of [^{123}I]IBZM in the brain.

The Neurocam, being a brain-dedicated instrument, has its detectors rigidly fixed in the gantry assuring mechanical stability. The size of the triangle within which the patient's head is positioned is constant. It is large enough to accommodate most adult heads but small enough to ensure close proximity imaging and hence better resolution. Unlike single-headed machines, patient positioning is easily and reproducibly done; it normally takes 1–2 min. The various Neurocam corrections necessary for artifact-free SPECT imaging, remain valid sufficiently long and the procedures to update them are relatively fast so that patient throughput is not adversely affected. In our institution, the tuning values of the PMTs and the energy corrections are updated every two weeks, and the COR and uniformity corrections are made every month.

Other three-headed systems have been designed for both head and body imaging (*1,10–12*). The size of their triangle is adjustable. They employ bigger camera heads to allow body SPECT data collection and hence the smallest triangle that can be achieved is greater than that of the Neurocam. The radius of rotation of the Neurocam (COR to collimator-face distance) is 12.25 cm compared to 13.2 cm for the Toshiba GCA-9300A system currently undergoing evaluation at our institution. However, use of fan beam collimators can offset the loss of resolution due to this greater collimator-to-patient distance.

Collimator choice is one of the most important factors that determine image quality in nuclear medicine. In spite of recommendations to use the HR collimator in SPECT (*3,13*), many centers with single rotating gamma cameras continue to use the GP (and some the high sensitivity) collimator, presumably because they consider the sensitivity to be of paramount importance. With the advent of multi-headed cameras, and the consequential gain in sensitivity, the loss of sensitivity accompanying the use of HR collimators should become easily acceptable. Our experience provides support for this recommendation. We routinely employ the HR parallel-hole collimators for most of our ^{99m}Tc-HMPAO studies with the Neurocam, and yet more counts are acquired than with a single-headed camera. Excellent anatomical representation of brain structures has been achieved with improved spatial resolution and hence reduced partial volume artifacts.

Fan beam collimators can further improve both resolution and sensitivity (*1,10,11*). The apparent system planar resolution improves by the magnification effect. Although, the resolution deteriorates with increasing source-to-collimator distance for both parallel and fan beam collimators, it deteriorates less for fan beam. For a point source in air, the sensitivity of a parallel-hole collimator is depth independent, but that of a fan beam collimator increases as the source moves away from the collimator face.

Although this paper is not reporting on the sensitivity, specificity, and accuracy of clinical diagnosis with the Neurocam, we hope to have demonstrated its clinical utility. A wide variety of clinical pathologies have been studied, among them multi-infarct dementia (MID) (10 patients) and demen-

tia of the Alzheimer's type (DAT) (10) compared to aged-matched normal volunteers (10), infantile autism (7), Gilles de la Tourette syndrome (20), epilepsy (9), stroke (15), TIAs (10), chronic fatigue syndrome (12), and others. In addition, split-dose SPECT protocols have been applied in neuroimaging, and neuroactivation studies with acceptable spatial resolution (*14*). Specifically, the Neurocam has been used to perform neuroactivation studies in normal volunteers (39), and in patients with Parkinson's disease (14), dementia (12), and epilepsy (5). Motor activation, intellectual performance and pharmacological intervention studies have been performed and the full results of these studies will be reported elsewhere.

Because of the ease of operation, ease of patient and data handling, and high image quality, we conclude that the Neurocam is an efficient and reliable, multi-slice brain imager for both routine and research purposes, in a wide variety of brain diseases. Following the administration of about 740 MBq of ^{99m}Tc-HMPAO, sufficient SPECT data to assure excellent image quality can be acquired in about 14 min, using high resolution parallel-hole collimators. The kinetic properties of newly available receptor ligands, e.g., [^{123}I]IBZM, and the high sensitivity of the Neurocam, fitted with general purpose collimators, render dynamic brain SPECT studies possible. With multi-headed systems such as the Neurocam, we expect that the role of SPECT in clinical practice and research will increase.

ACKNOWLEDGMENT

The authors are grateful to GE/CGR for its support.

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