ment in SPECT perfusion scores corresponded to improvement in clinical signs and symptoms. In our study, we found an association between the finding of severe perfusion defects and the outcome of death, although clinical findings of unresponsiveness secondary to vasospasm remained the best predictor of death as an outcome. There did not appear to be a correlation between SPECT findings and less severe outcomes; this may, however, be due to our small sample size.

CONCLUSION

The results of this investigation would indicate that SPECT should be considered as the first test for the detection of clinically suspected vasospasm and may obviate the need for invasive studies before the onset of treatment. In addition, SPECT may aid in the identification of those patients with a poor prognosis. In this preliminary study, we found that SPECT brain perfusion studies substantially contributed to the diagnosis of vasospasm complicating subarachnoid hemorrhage and allowed early initiation of specific therapy to treat this serious illness.

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HMPAO Brain SPECT in Acute Carbon Monoxide Poisoning

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Technetium-99m-hexamethylpropylene amine oxime (HMPAO) brain images with fanbeam SPECT, in combination with surface three-dimensional display, were used to detect basal ganglion and cerebral cortex anomalies in the acute phase of carbon monoxide (CO) poisoning. **Methods:** Ten patients, aged 16–29 yr, with acute CO poisoning and no past history of neurologic disorders were enrolled in this study. After oxygen treatment, all 10 patients were investigated using ^{99m}Tc-HMPAO brain images with fanbeam SPECT and surface three-dimensional display. Meanwhile, 6 of 10 patients also received a brain CT scan. **Results:** CT scan findings were negative in all 6 patients. Fanbeam SPECT demonstrated unilateral or bilateral hypoactivity of basal ganglia in 6 patients. Local hypoactivity anomalies were found in the brain cortex of 7 patients, using surface three-dimensional display of the brain. Only 2 of 10 patients had normal ^{99m}Tc-HMPAO brain images. **Conclusion:** This study suggests that, in comparison with traditional brain imaging techniques, ^{99m}Tc-HMPAO brain imaging with fanbeam SPECT in combination with surface three-dimensional display is a better tool for early detection of regional cerebral anomalies in acute CO poisoning.

Key Words: technetium-99m-hexamethylpropylene amine oxime; fanbeam collimator; SPECT; surface three-dimensional display; carbon monoxide poisoning

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Acute carbon monoxide (CO) poisoning is a frequent and often fatal event. Of those who survive, 10%–40% suffer permanent neuropsychiatric complications (*1–3*), the nature of which cannot be predicted in the acute phase by clinical, EEG or brain CT scan findings (*1,3,4*). Brain imaging with ^{99m}Tc-hexamethylpropylene amine oxime (HMPAO) has been used for the assessment of regional cerebral blood flow (rCBF) and has proven accurate for detecting various neurological and psychiatric diseases (*5,6*).

SPECT is essential for depicting brain abnormalities, because it improves image contrast by separating overlapping structures (*7,8*). Particularly when a fanbeam collimator is used to replace the conventional parallel-hole collimator, both system resolution and sensitivity improve by approximately 20% (*9,10*). In addition, if the fanbeam collimator has an FWHM close to 6.5 mm (*11*), deeper lesions within the brain, such as lesions of the basal ganglia, can be clearly demonstrated. However, when brain lesions are evaluated by SPECT, the interpreter must bring together every slice of the transaxial, coronal and sagittal sections to make a whole for accurate localization of lesions. To avoid this, surface three-dimensional images of the brain can be used. Surface three-dimensional images can enhance continuity of structures and improve understanding of spatial relationships (*12–14*). Although a standard surface three-dimensional display cannot depict lesions within the brain, such as those of the basal ganglia (*14,15*), this technique has been clinically applied to the evaluation of rCBF in patients who have suffered stroke (*14–16*), seizure (*16*), depression (*17*) or slow progressive apraxia (*7*).

TABLE 1
Patient Results

Patient no.	Age (yr)	Sex	Neurologic signs at admission	COHb (%)	Technetium-99m-HMPAO brain image: Fanbeam SPECT (basal ganglia)	Technetium-99m-HMPAO brain image: Surface three-dimensional display (cerebral cortices)	Brain CT scan	Neuropsychiatric sequelae
1	26	M	Loss of consciousness	13.5	Bil	Bil F-P-T	N	Parkinsonism, disorientation, memory impairment
2	19	M	Loss of consciousness	10.2	L	Bil P	N	Parkinsonism, confusion
3	16	M	Conscious disturbance	1.7	N	Bil P	N	Disorientation
4	20	F	Loss of consciousness	14.9	Bil	Bil F-P-O	N	Parkinsonism, confusion, blurred vision
5	17	F	Loss of consciousness	13.7	R	Bil P	N	Parkinsonism, disorientation
6	17	M	Loss of consciousness	9.7	N	Bil P-T-O	N	Disorientation, memory impairment, blurred vision
7	19	M	Headache, dizziness	9.6	L	Bil F-P-T	—	Parkinsonism, confusion, memory impairment
8	20	F	Loss of consciousness	5.5	R	N	—	Parkinsonism
9	25	M	None	1.2	N	N	—	None
10	29	M	Dizziness	3.9	N	N	—	None

Bil = bilateral hypoperfusion; L = left-side hypoperfusion; R = right-side hypoperfusion; F = frontal lobe; P = parietal lobe; T = temporal lobe; O = occipital lobe; N = normal.

In this study, we investigated the potential of ^{99m}Tc-HMPAO brain images to detect cerebral anomalies in the acute phase of CO poisoning.

MATERIALS AND METHODS

Patients

Ten patients (3 women, 7 men; aged 16–29 yr) with acute CO poisoning and no past history of neurologic disorders were enrolled in this study (Table 1). When the CO-poisoned patients were found, they were transferred to our emergency room immediately (the interval was 0.5–1 hr). On admission, none of the patients had any symptoms or signs of active psychiatric disease. Toxicology screens were performed to rule out poisoning from other drugs or chemicals. Blood COHb values were measured immediately, and then either nasal or hyperbaric oxygen therapy was administered. After oxygen treatment, all patients had normal blood COHb values and no neurologic signs of toxicity. Two to 5 hr after CO intoxication, all 10 patients were investigated using ^{99m}Tc-HMPAO brain images with fanbeam SPECT and surface three-dimensional display. Meanwhile, 6 of the 10 patients also received a brain CT scan for comparison. All brain imaging studies, including ^{99m}Tc-HMPAO brain images and brain CT scans, were performed on the day of admission.

Technetium-99m-HMPAO Brain Images

Technetium-99m-HMPAO was prepared from a freeze-dried kit (Ceretec, Amersham International, Amersham, UK) by the addition of about 1250 MBq of freshly eluted ^{99m}Tc-pertechnetate to 5 ml saline solution. The solution was injected no more than 30 min after preparation.

Patients were placed in a supine position in a quiet room with dimmed lights and were allowed to relax with their eyes closed for 15 min before intravenous administration of 1110 MBq (30 mCi) ^{99m}Tc-HMPAO. After injection of ^{99m}Tc-HMPAO, the patients were asked not to move or to talk for at least 10 min. The scan was performed 90–120 min after injection. During imaging, patients were positioned supine on the imaging table with their forehead and chin restrained.

The scanning equipment consisted of a rotating, large field-of-view, dual-head gamma camera (Helix HR, Elscint Ltd., Haifa, Israel) fitted with a fanbeam collimator. Data were collected in a 64 × 64 matrix with 1.3 zooming, through a 360° (180° for each head) rotation at 3° intervals, for 25 sec per arc interval. Approximately 7.5 million counts were acquired. The SPECT images (coronal, sagittal and transaxial sections) were reconstructed using a Metz filter (power 5.00), backprojection and attenuation correction. The transaxial sections were reoriented parallel to the base of the brain to obtain sagittal and coronal reconstructions. Surface three-dimensional displays were reconstructed from transaxial SPECT data with a processing time of 3–5 min. The threshold value was set at 50% (*15,18*). The spatial resolution of the camera with fanbeam collimator, through air, was 6.3 mm FWHM.

To identify local areas of abnormal hypoperfusion, two observers who were blind to clinical information performed a visual interpretation of the SPECT images and surface three-dimensional display results. Normal ^{99m}Tc-HMPAO brain imaging findings consisted of homogenous rCBF in the gray matter of basal ganglia and cerebral cortex without focal hypoactivity or visible asymmetry.

RESULTS

The detailed results of the patients are shown in Table 1. Eight of the 10 patients had abnormal ^{99m}Tc-HMPAO brain images (diagnostic sensitivity 80%) on fanbeam SPECT (Fig. 1A) and/or surface three-dimensional display (Fig. 1B). Fanbeam SPECT of the brain demonstrated unilateral or bilateral hypoactivity of basal ganglia in 6 patients (diagnostic sensitivity 60%) (Fig. 2). Surface three-dimensional display of the brain revealed local hypoactivity anomalies in the brain cortex of 7 patients (diagnostic sensitivity 70%) (Figs. 3A, B). The most commonly involved areas were the parietal lobes (Table 1). Six

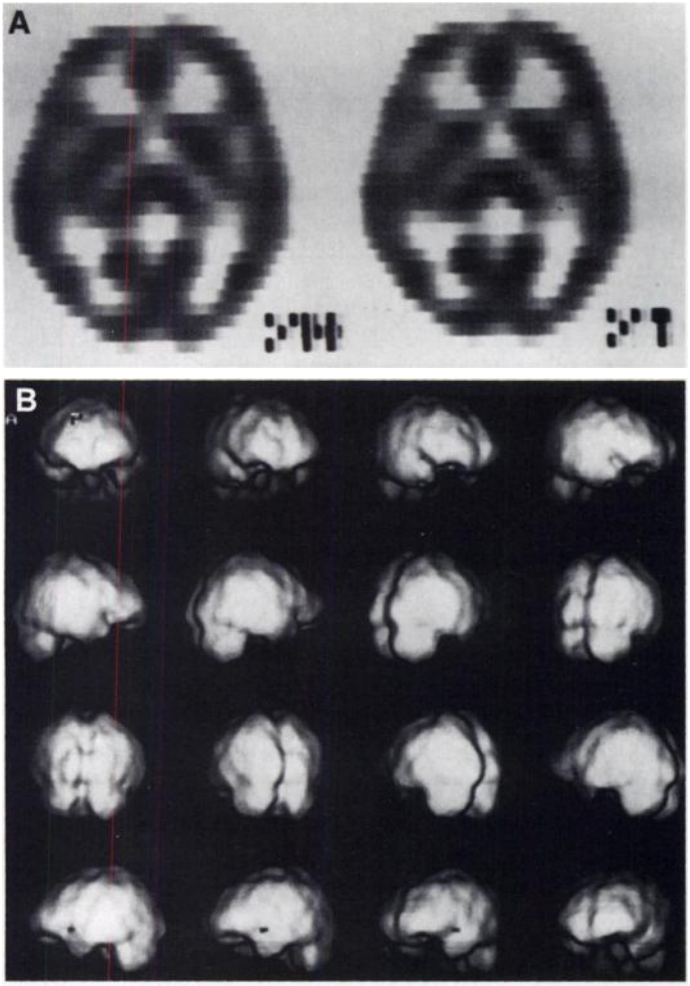

FIGURE 1. A 25-yr-old man (Patient 9). The findings of ^{99m}Tc-HMPAO brain images were negative. (A) Fanbeam SPECT (transaxial slices) of the brain and (B) surface three-dimensional display of the brain reveal homogenous rCBF in the gray matter of basal ganglia and cerebral cortex without focal hypoactivity or visible asymmetry.

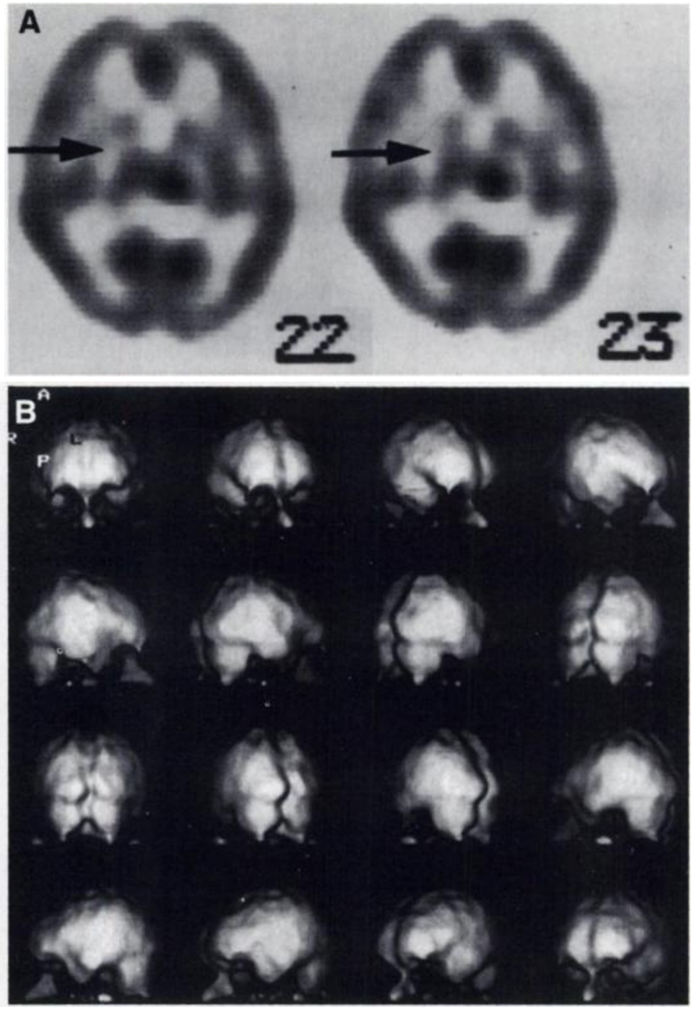

FIGURE 2. A 20-yr-old woman (Patient 8). (A) Fanbeam SPECT of the brain demonstrates hypoperfusion in the right basal ganglia (arrows). (B) Surface three-dimensional display of the brain does not reveal significant local hypoperfusion areas in the cerebral cortex.

patients with abnormal fanbeam SPECT or three-dimensional display findings also received a brain CT scan. CT scans were normal in all 6 patients (Fig. 3). The patients with high COHb values and severe neurologic signs (loss of consciousness) on admission had a high incidence of abnormal ^{99m}Tc-HMPAO brain imaging findings (Table 1).

DISCUSSION

CO intoxication causes a wide variety of neurologic and psychiatric disorders (*1–4*). The most common neuropathologic findings in acute and delayed CO encephalopathy are ischemia and necrosis of basal ganglia (globi pallidi). Less frequent findings include spongy necrosis of cerebral cortices (*12*). Damage in the globi pallidi and cerebral cortex can usually be demonstrated by serial CT or MRI studies (*4,19–21*). However, structural changes may not be apparent in the early phase of CO intoxication, which may lead to diagnostic difficulty and delayed or inappropriate treatment (*1,3,4*).

One previous study using traditional ^{99m}Tc-HMPAO brain SPECT reported regional cerebral cortical hypoactivity in 5 of 12 (42%) patients with CO intoxication (*22*). The results are in agreement with the findings of a few available cerebral function perfusion studies: Abnormal cerebral cortical hypoperfusion follows CO intoxication (*9,23*). Our study shows results similar to the previous ^{99m}Tc-HMPAO brain SPECT report (*22*) but better diagnostic sensitivity. Decreased rCBF in the brain cortex of 7 of 10 (70%) patients was easily detected by surface three-dimensional display of the brain (Table 1).

Hypoactivity or necrosis of basal ganglia (globi pallidi) is highly suggestive of CO intoxication. However, in previous studies, hypoactivity lesions located in the cerebral cortex could be demonstrated, whereas abnormal rCBF lesions within basal ganglia could not be detected (*22,23*). Focal cerebral cortical hypoperfusion demonstrated by surface three-dimensional display is relatively nonspecific. Similar hypoperfusion anomalies in the cerebral cortex can be found in a variety of acute neurologic disorders, including postanoxic syndrome due to cardiac arrest, hypoglycemia, cerebral infarction, multi-infarct dementia and Alzheimer's and Parkinson's disease (*23,24*). Therefore, in loss of consciousness of unknown origin, ^{99m}Tc-HMPAO brain images would not provide great help in the retrospective diagnosis of CO poisoning.

In a previous study, using traditional brain imaging techniques, there was no significant correlation of brain imaging findings to blood CO level and clinical signs at admission (*22*). However, we found that the patients with high COHb values and severe neurologic signs (loss of consciousness) on admission had a high incidence of abnormal brain ^{99m}Tc-HMPAO findings (Table 1). If the threshold value of blood COHb was defined as >3.9% (seven patients), all seven patients (100%) had abnormal findings on SPECT and/or three-dimensional display, including six of seven patients (86%) with abnormal

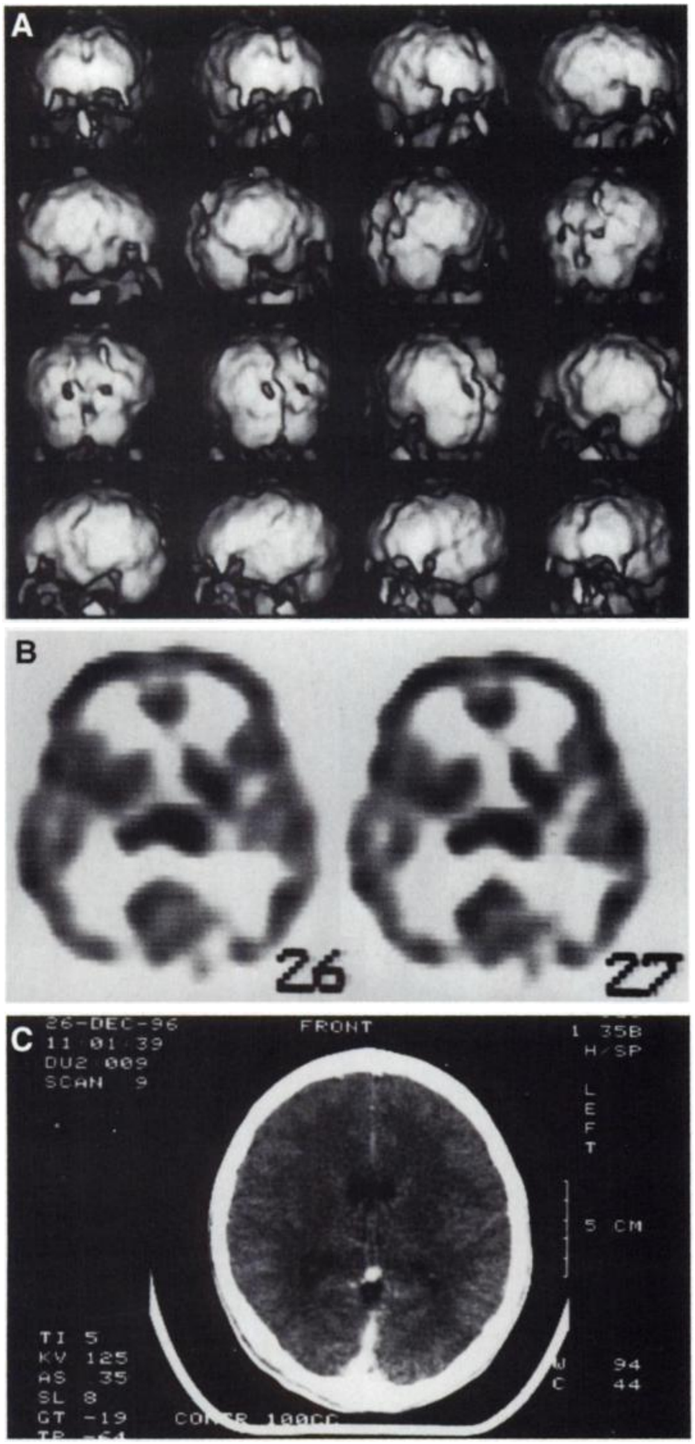

FIGURE 3. A 17-yr-old man (Patient 6). (A) Fanbeam SPECT of the brain does not demonstrate significant hypoperfusion in the basal ganglia. (B) Surface three-dimensional display of the brain reveals local hypoperfusion in the brain cortex, especially in the bilateral parietal-temporal-occipital lobes. (C) Brain CT scan does not show any significant abnormalities in the basal ganglia or cerebral cortex.

SPECT findings and six of seven patients (86%) with abnormal three-dimensional display findings. If the threshold value of blood COHb was defined as >5.5% (six patients), all patients (100%) had abnormal findings on SPECT and/or three-dimensional display, including five of six patients (83%) with abnormal SPECT findings and six of six patients (100%) with abnormal three-dimensional display findings.

This study suggests that ^{99m}Tc-HMPAO brain images with fanbeam SPECT, in combination with surface three-dimensional display, can be a sensitive tool for detecting early regional cerebral cortex and basal ganglia anomalies in acute CO poisoning. In addition, our findings may be related to neuropsychiatric sequelae (Table 1). We found that all six patients with basal ganglia hypoperfusion lesions developed symptoms or signs of parkinsonism, and two patients with occipital lobe hypoperfusion lesions developed blurred vision. In addition, two patients without hypoperfusion lesions did not develop any neuropsychiatric sequelae.

In conjunction with fanbeam SPECT and surface three-dimensional display, ^{99m}Tc-HMPAO brain images should be a standard method to evaluate deeper lesions within the brain, such as those of the basal ganglia, and to better understand spatial relationships of the brain cortex. It can be a sensitive tool for detecting brain anomalies and for predicting patient outcome in acute CO poisoning.

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