

NUCLEAR BRAIN IMAGING: STROKE

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INTRODUCTION

According to the American Stroke Association, someone in the United States has a stroke every 53 seconds. Of these approximately 600,000 victims 160,000 will die. Stroke is our nation's third leading killer and a primary cause of disability. The majority of all strokes are caused by focal ischemia, followed by intracerebral hematomas and subarachnoid hemorrhage.¹ Signs of stroke may include:

1. Sudden numbness or weakness of the face, arm or leg, especially on one side of the body
2. Sudden confusion, difficulty speaking or understanding
3. Sudden difficulty walking, dizziness, loss of balance or coordination
4. Sudden difficulty seeing with one or both eyes
5. Sudden, severe headache of unknown cause²

A number of physiologic processes are related to stroke. Transient ischemic attacks (TIAs) and reversible ischemic neurologic deficits (RINDs) will produce signs consistent with stroke. Fortunately, these signs are usually temporary and will resolve given enough time. More insidious than either TIAs or RINDs is multi-infarct dementia (MID). MID is a progressive dementia characterized by repeated ischemic episodes. Individual episodes may go unnoticed, but the cumulative effect leads to signs and symptoms similar to those found in patients suffering from Alzheimer's disease.

PHYSIOLOGY RELATED TO NUCLEAR MEDICINE IMAGING

BLOOD-BRAIN BARRIER

No discussion of nuclear medicine brain imaging would be complete without a brief discussion of the *blood-brain barrier*. In most tissues, the capillaries have a number of mechanisms facilitating the passage of nutrients, wastes, and other metabolites between blood and tissue. Within the brain, however, the capillary walls are far more restrictive in what material they will allow to pass. Believed to be a combination of a tight intracellular junction of endothelial cells in the cerebral capillaries, a lack of extracellular fluid space, a lack of pinocytosis, and limited transport mechanisms, the blood-brain barrier protects the brain from variations in blood composition and helps restrict the entry of potentially toxic compounds.³ Hence, the blood-brain barrier describes a collaborative phenomena, one that is obviously not an anatomic structure that can be easily excised for examination.

The barrier generally excludes macromolecules, protein-bound substances, and hydrophilic compounds from entering brain tissue. For those compounds necessary for cell survival, methods of active transport across the intact blood-brain barrier have evolved. For example, glucose—the principal source of energy for the brain—is actively transported into brain cells to meet energy demands. However, the blood-brain barrier proves less restrictive with lipophilic compounds. These compounds are able to passively diffuse into brain cells by dissolving in cell membranes and emerging within the cells.⁴

Certain pathologic conditions, such as tumor, inflammation, and stroke, can cause a disruption to the blood-brain barrier. The blood-brain barrier loses its selective permeability; a number of molecules, including *hydrophilic imaging agents*, can find their way from the blood into the brain. In fact, uses of early nuclear medicine brain imaging agents relied upon a disrupted blood-brain barrier to identify a number of pathologic processes. More recently developed radiopharmaceuticals are lipophilic and rely upon passive diffusion or are similar in structure to substances that are actively transported into viable brain tissue.

NUCLEAR MEDICINE BRAIN IMAGING AGENTS

Nuclear medicine brain imaging agents can localize and assess the extent of stroke. A number of different compounds have been used extensively for this purpose. Each compound has its own unique method of localization. However, many are sufficiently similar that they can be classified according to their properties or means of localization. Three such classifications are:

1. Hydrophilic (non-diffusible)
2. Lipophilic (diffusible)
3. Metabolic

HYDROPHILIC COMPOUNDS

Hydrophilic compounds were the first developed in nuclear medicine imaging. These compounds depended upon a compromised blood-brain barrier to localize in damaged areas of the brain. Because the abnormal areas tended to concentrate the hydrophilic compound and normal areas excluded their entry, abnormal areas could be identified as "hot spots."

Among the first brain imaging agents used in the detection of stroke and other cerebral pathologies were mercurial compounds such as mercury 197, mercury 203-labeled chlormerodrin, and iodine 131-HSA (human serum albumin).⁵ These compounds were administered intravenously in amounts ranging from a few hundred microcuries to one millicurie,⁶ then scanned with a rectilinear scanner to localize blood-brain barrier defects (including those caused by stroke). These compounds and instruments have not been used in nuclear medicine for a number of years and are only mentioned here as a historic curiosity.

Hydrophilic technetium compounds. More recently, the hydrophilic compounds technetium 99m pertechnetate ($^{99m}\text{TcO}_4$), technetium 99m-diethylenetriaminepenta-acetic acid (DTPA), and technetium 99m-glucetate have been widely used to detect and assess stroke. All ^{99m}Tc -labeled compounds have the advantage of very low amounts of particulate radiation, a relatively short physical half-life of 6 hours, an almost ideal imaging energy for modern nuclear medicine equipment (140 keV), and good and inexpensive availability in the common molybdenum 99/technetium 99m generator. (The first two attributes are patient exposure considerations.)

Brain imaging for stroke using these technetium compounds predates the availability of single photon emission computed tomography (SPECT). Hence, imaging studies at that time were acquired with two-dimensional planar imaging. The imaging procedure

followed for the three technetium compounds was very similar—a two-stage study in which a patient received an angiographic flow study, followed 1½ to 3 hours later with planar imaging. The flow study was usually performed from the anterior projection (face closest to collimator) unless there were indications that the stroke may have been posterior in nature. In addition to recording the flow study on film, the first 30 to 60 seconds of the flow was saved to a computer for quantitative evaluation. Regions of interest were drawn around the cerebral hemispheres and carotid arteries. Contralateral views were compared for symmetry and were often graphically displayed on a time-activity curve. Delayed images were obtained 1½ to 3 hours post injection, depending upon the radiopharmaceutical used. Anterior, posterior, right and left lateral, and vertex views were routinely obtained.

^{99m}Tc pertechnetate. Of these hydrophilic compounds, ^{99m}Tc pertechnetate was the first imaging agent used. It was extremely inexpensive and easy to prepare. However, ^{99m}Tc pertechnetate has a notably slow renal clearance. This disadvantage results in high background activity (low target-to-nontarget ratio). ^{99m}Tc pertechnetate also accumulates in the choroid plexus, making it necessary to administer a blocking agent to avoid confusing choroid plexus uptake with a lesion. For ^{99m}Tc pertechnetate studies, the typical delay between the flow study and static imaging was approximately three hours. This allowed for the maximum clearance of background activity by the kidneys.

^{99m}Tc -DTPA. ^{99m}Tc -DTPA was the next agent used in nuclear medicine brain imaging. This compound has a better target-to-nontarget ratio than ^{99m}Tc pertechnetate because it is rapidly cleared from the circulatory system by glomerular filtration. Although the rapid renal clearance significantly reduces background activity, it also greatly reduced the activity available for imaging. Consequently, images often took a considerable amount of time to acquire. The typical delay between the flow study and static imaging was about 1½ hours. The rapid clearance of ^{99m}Tc -DTPA by the kidneys necessitated the early return.

^{99m}Tc -glucetate. ^{99m}Tc -glucetate was the third hydrophilic agent used widely. As with ^{99m}Tc -DTPA, ^{99m}Tc -glucetate is rapidly cleared from the circulatory system by the kidneys, although by different mechanisms. This rapid clearance resulted in a significant reduction in background activity while providing enough ^{99m}Tc -glucetate to achieve a better target-to-nontarget ratio than either ^{99m}Tc pertechnetate or ^{99m}Tc -DTPA. This improved ratio led to faster acquisition times and higher quality images. Technologists enjoyed more latitude in scheduling delayed images for these patients. Due to the low background activity and respectable target-to-nontarget ratio, a patient's delayed images could be performed 2 to 3 hours post injection.

TABLE 1. Hydrophilic Compounds Used for Brain Imaging

Imaging Agent	Admin. Activity	Rec. Delay	Other
^{99m}Tc -Pertechnetate	10-20 mCi	3 h	Excessively high background; choroid plexus takes up pertechnetate and needs to be blocked with perchlorate before imaging
^{99m}Tc -DTPA	10-20 mCi	1.5 h	Rapid renal clearance necessitates a quick return for delayed images
^{99m}Tc -Glucaptate	10-20 mCi	2-3 h	Efficient renal clearance and a good target-to-nontarget ratio permitted; flexibility in scheduling

Timing. Detection of stroke using hydrophilic radiopharmaceuticals depends upon a number of factors, the most important of which is the time interval between the stroke and the imaging. In the first few days following the stroke, only 20% of patients will have detectable lesions. The majority of strokes do not visualize until 7 to 10 days post injury. The size and position of the lesion will greatly influence detectability. For example, small strokes and those occurring in the brain stem are frequently missed with static imaging. After 3 weeks post infarction, approximately 75% of strokes can be visualized with hydrophilic compounds. They will remain positive for variable periods of time but will generally decrease in intensity after 1 month and return to normal by 6 weeks after the stroke.⁷

Current uses. The lack of immediate and conclusive evidence, coupled with the arrival of computed tomography (CT) and magnetic resonance imaging (MRI), hastened the end of using hydrophilic brain imaging compounds for the diagnosis and assessment of stroke. Today, ^{99m}Tc pertechnetate is primarily used for kit preparation of other radiopharmaceuticals. However, this compound still has uses for thyroid imaging, Meckel's diverticulum imaging, and the labeling of red blood cells. ^{99m}Tc -DTPA is primarily used for estimations of glomerular filtration rates, but this compound also has considerable utility in dual-phase brain tumor imaging, aerosol lung imaging, and renal imaging for obstructive uropathies. ^{99m}Tc -glucaptate, once the best of the hydrophilic brain imaging agents, is hardly used in the modern nuclear medicine laboratory. However, this compound is still available as a renal imaging agent for which it is useful in assessing obstructive uropathies and evaluating the presence or absence of space-occupying renal lesions.

LIPOPHILIC COMPOUNDS

Lipophilic compounds were the next generation of nuclear medicine radiopharmaceuticals to find wide use as brain imaging agents. These compounds crossed the intact blood-brain barrier in proportion to regional blood flow. The lipophilic compounds eventually developed for commercial use would maintain this distribution for a period of time sufficient enough to permit imaging. Planar images could be obtained with these agents. When SPECT technology became commercially available, however, it provided a more thorough analysis of brain tissue. Technically speaking, SPECT technology pre-dates CT. Experimentation was done with SPECT in the 1940's but there was no use identified for it. Eventually researchers recognized its applicability in radiology and helped develop it into CT. Generally speaking, SPECT became mainstream technology in nuclear medicine in the early to mid-1980's.

Because these agents accumulate within the brain in proportion to regional blood flow, precautions should be taken to avoid over- or understimulating the brain. Some routine injection precautions include:

- Keep patient's eyes open during injection (hold an eyelid open if the patient is not able to do so)
- No bright lights-low lighting only
- No loud noises
- No music

These conditions should be maintained for at least 15 minutes after injecting lipophilic imaging agents.⁸

N-isopropyl-p-iodoamphetamine (^{123}I -IMP). ^{123}I -IMP was the first lipophilic compound to gain widespread use. It had an extremely high first-pass extraction in the brain of 92%.⁹ However, peak brain activity does not occur until approximately 20 minutes post injection. This phenomenon appears to be correlated with an initial, substantial lung uptake and clearance rate.¹⁰

A longer physical half-life relative to ^{99m}Tc (13.2 hours vs 6.0 hours) contributed to reducing the activity being administered for imaging purposes. Generally speaking, radionuclides with longer physical half lives increase the radiation burden to patients. To offset the increased radiation burden brought about by the longer physical half life, the activity administered is usually reduced. This reduced activity became a liability for ^{123}I -IMP imaging because SPECT acquisitions favor increased activities (ie, more detected radiation events). Only 2 to 3 mCi were administered intravenously when adhering to routine precautions. As with many radioiodinated compounds, it was recommended that Lugol's solution be administered to block activity from entering the thyroid gland.

Stroke imaging with ^{123}I -IMP required two sets of images. The first set of images were started between 20 to 60 minutes post injection because the distribu-

tion of ^{123}I -IMP is relatively constant during that time.¹¹ The second set of images was acquired at approximately 3 hours post injection.

Both sets of images were compared to assess the possibility of stroke. Early images demonstrating areas of decreased uptake that later "filled in" with delayed images were indicative of viable tissue within ischemic regions. Stroke was more likely with images in which areas of decreased activity were present on both early and delayed images.¹² *Luxury perfusion*, a reactive hyperemia surrounding areas of recent brain infarct,¹³ does not seem to create areas of increased ^{123}I -IMP uptake as it does with other lipophilic agents.¹⁴ Despite the advantage of differentiating between areas of cerebral infarct and cerebral ischemia with this product, it has been withdrawn from the market and is thus, no longer commercially available in the United States.

$^{99\text{m}}\text{Tc}$ -HMPAO (*hexamethylpropylene amine oxime*) was the next lipophilic agent to gain widespread acceptance. As with other lipophilic agents, $^{99\text{m}}\text{Tc}$ -HMPAO is distributed within the brain in proportion to regional blood flow. $^{99\text{m}}\text{Tc}$ -HMPAO comes in a kit for preparation in the clinic setting. $^{99\text{m}}\text{Tc}$ -HMPAO is extremely sensitive to oxidation, so caution must be taken to prevent air from entering the vial. Approximately 10 to 30 mCi of $^{99\text{m}}\text{Tc}$ -pertechnetate in a 5-mL volume are added to the kit. In order to minimize the presence of oxidants within the pertechnetate, the $^{99\text{m}}\text{Tc}$ -pertechnetate must be less than 2 hours old. Additionally, the generator must have been previously eluted within 24 hours of the 2-hour elution. A tagging efficiency greater than 80% is considered acceptable. Initially, the shelf life of $^{99\text{m}}\text{Tc}$ -HMPAO was approximately 30 minutes because of a tendency to decompose to a less lipophilic compound however, the addition of methylene blue and a phosphate buffer have lengthened the shelf life to approximately 4 hours.

Approximately 20 to 30 mCi of $^{99\text{m}}\text{Tc}$ -HMPAO are administered intravenously following routine injection precautions. Images are obtained after 30 to 60 minutes post injection to allow background levels, especially within the scalp, to minimize. Distribution within the brain remains constant for the next 24 hours,¹⁵ so technologists have considerable latitude in scheduling patients.

Unlike ^{123}I -IMP, $^{99\text{m}}\text{Tc}$ -HMPAO only requires one set of images for stroke imaging. Areas of the brain affected by stroke are typically demonstrated as areas of absent or diminished uptake. *Luxury perfusion* has occasionally been noted as areas of increased or normal uptake.¹⁶⁻¹⁸ Correlation with other imaging modalities may be helpful in cases demonstrating *luxury perfusion*.

$^{99\text{m}}\text{Tc}$ -ethyl cysteinate dimer ($^{99\text{m}}\text{Tc}$ -ECD). $^{99\text{m}}\text{Tc}$ -ECD is the most recent lipophilic agent approved for brain imaging. As with ^{123}I -IMP and $^{99\text{m}}\text{Tc}$ -HMPAO, $^{99\text{m}}\text{Tc}$ -ECD is distributed throughout the brain in proportion to regional blood flow. It has been approved for

only a few years in the United States, but it has been used internationally for some time.

Approximately 10 to 20 mCi of $^{99\text{m}}\text{Tc}$ -ECD is injected intravenously following routine injection precautions. Blood clearance and brain uptake is rapid, but it has been noted that brain clearance may approach 12.5% during early imaging. However, this early clearance does not seem to compromise image interpretation.¹⁷

As with $^{99\text{m}}\text{Tc}$ -HMPAO, brain imaging with $^{99\text{m}}\text{Tc}$ -ECD only requires obtaining one set of images for stroke imaging. Areas of the brain affected by stroke are typically demonstrated as areas of absent or diminished uptake. Unlike $^{99\text{m}}\text{Tc}$ -HMPAO, $^{99\text{m}}\text{Tc}$ -ECD does not seem to change its distribution secondary to *luxury perfusion*^{14,16,18} and will continue to demonstrate stroke as areas of decreased or absent uptake.

Imaging considerations. Planar images can be obtained showing the distribution of lipophilic compounds in the stroke patient, but there is a substantial risk that normally perfused tissue may obscure areas of decreased or absent perfusion. Hence, SPECT technology is the method of choice for obtaining brain images for the stroke patient. Considering the speed with which computer technology advances, it is difficult to prescribe parameters for SPECT acquisition and playback. Minimal guidelines available now may be obsolete in a year. In addition, other factors such as patient comfort and cooperation, scheduling constraints, physician preferences, and the limitations of imaging systems must be considered.

Foremost, technologists should maximize counts and resolution while creating as little patient discomfort as possible. Unfortunately, this combined goal is difficult to achieve; the patient may be unable to tolerate a procedure that maximizes counts and resolution to the satisfaction of the physician and technologist. As a compromise, common protocols typically call for a 64 x 64 matrix set for approximately 60 stops with a 360-degree rotation. This protocol will usually collect a sufficient number of counts for manipulation and playback regardless of the lipophilic agent being used. Newer multihead systems, coupled with the higher administered activities of $^{99\text{m}}\text{Tc}$ -HMPAO and $^{99\text{m}}\text{Tc}$ -ECD (10-30 mCi vs 2-3 mCi for ^{123}I -IMP), will generate sufficient counts to increase the acquisition parameters to a 128 x 128 matrix. Early and Sodee detail a number of acquisition parameters that are worth reviewing before adopting or changing a protocol.¹⁹

Collimators. *Low-energy, all-purpose collimators* are commonly chosen because they provide a good balance between sensitivity and resolution and are generally preferable to the high-resolution or high-sensitivity collimator. Another—but less common—choice of collimator for brain imaging is the *fan beam collimator*. Fan beam collimators are constructed so that the holes focus on an imaginary line as opposed to pinhole or converging collimators that focus on a point. The goal of the fan beam collimator is to increase both the sensitivity and resolu-

tion simultaneously. Resolution can be dictated by hole size and placement. Increasing the area of the crystal involved in image acquisition enhances sensitivity. Using fan beam collimators will result in considerable distortion of the acquired image. This is corrected during playback with software that is supplied by the imaging system manufacturer.

Playback and data manipulation. The specific nuances of playback and data manipulation will often be dependent upon the individual preferences of the interpreting physician. The playback results will display the images in the coronal, transaxial, and sagittal projections. With stroke patients, abnormalities are identified as areas of decreased or absent uptake not apparent on the contralateral side. The two most useful projections are the coronal and transaxial, because both hemispheres may be viewed simultaneously. With the sagittal view, only one hemisphere of the brain is seen at a time.

Acute stroke phase. Imaging in the acute phase of stroke with lipophilic compounds is fairly straightforward. ^{123}I -IMP, $^{99\text{m}}\text{Tc}$ -HMPAO, and $^{99\text{m}}\text{Tc}$ -ECD will demonstrate regions of the brain involved in stroke as areas of decreased or absent uptake. Nuclear medicine brain imaging is dramatically more sensitive than CT in detecting stroke within the first 8 hours of onset (90 percent vs 20 percent).²⁰ Defects on SPECT are often larger than those seen on CT. Possible reasons for this include volume defects due to limited system resolution²¹ or ischemic brain tissue at risk for infarction.²²

Subacute stroke phase. Imaging in the subacute phase of stroke may become more complicated due to luxury perfusion. As discussed previously, $^{99\text{m}}\text{Tc}$ -HMPAO has a demonstrated tendency to localize within areas of luxury perfusion, whereas $^{99\text{m}}\text{Tc}$ -ECD does not. Consequently, $^{99\text{m}}\text{Tc}$ -HMPAO may disguise areas of the brain involved in stroke by making them appear as normal or of increased uptake. Crossed cerebellar diaschisis is demonstrated as decreased cerebellar perfusion contralateral to the stroke and is often seen in the acute and subacute phases. Cerebellar diaschisis may be useful to look for in situations where increased or normal uptake secondary to luxury perfusion is suspected.^{23,24}

METABOLIC COMPOUNDS

Positron emission tomography (PET) takes advantage of the 0.511 MeV annihilation photons that are given off when a positron interacts with an electron. Traditional PET-dedicated imaging devices were composed of a ring of uncollimated detectors. Because annihilation events are emitted at 180 degrees from each other, the uncollimated system could distinguish true counts from background by simultaneously registering both annihilation events.

PET has been useful in the diagnosis and follow-up of numerous different pathologic conditions. Unfortunately, PET was slow to be adopted by mainstream medicine for the following reasons:

- Extreme expense of owning and operating the necessary equipment
- Insurers reluctance to reimburse for its services
- Archaic regulatory mechanisms set before the advent of PET

In recent times, many of these regulatory barriers have been updated. Insurers are now aware of the efficacy of PET procedures and are beginning to reimburse for its services. Also, recent technologic breakthroughs are decreasing expenses placing PET technology within reach of the routine nuclear medicine laboratory.

TABLE 2. PET Radionuclides

Radionuclide	Half-Life
^{11}C	20.4 h
^{13}N	10.0 h
^{15}O	122 sec
^{18}F	109.8 min

PET radionuclides are cyclotron-produced, and many are identical to materials normally found in the body.²⁵ Although this characteristic is inherently attractive for use in measuring certain metabolic activities, the transitory nature of many PET radionuclides make it less desirable. It is very difficult to manipulate or manufacture the short-lived radionuclides into other radiopharmaceuticals.

Fluorine 18 fluorodeoxyglucose (^{18}F -FDG). Viable brain cells will actively transport glucose from the circulation for use as an energy source. This observation eventually led to the development of ^{18}F -FDG. ^{18}F -FDG lasts considerably longer than other cyclotron-produced PET radionuclides. The nearly 2-hour half-life gives laboratory personnel sufficient time to formulate ^{18}F into more complex compounds. Furthermore, ^{18}F -FDG is different enough from glucose that once it is taken into the brain cell, it becomes "stuck" in the metabolic process where it can be imaged for a number of hours.

Approximately 5 to 10 mCi of ^{18}F -FDG are administered intravenously, and images are obtained 40 minutes later.²⁶ The distribution of FDG in the brain is directly related to perfusion and metabolism. Areas of stroke can be identified as areas of decreased or absent uptake. As with various other nuclear medicine procedures, ^{18}F -FDG imaging can successfully demonstrate areas of altered physiology before CT and MRI can detect morphologic alterations.²⁷ CT and MRI excel at anatomy (morphology), yet nuclear medicine still detects the physiological changes before morphological changes become apparent. In stroke imaging cases,

TABLE 3. Common Radiopharmaceuticals

Radionuclide	Imaging Agent	Classification	Method of Localization	Imaging Method	Activity Administered	Time to Imaging
^{99m}Tc	Pertechnetate	Hydrophilic	BBB compromise	Planar	10-20 mCi	Immediate flow with 3-hour wait for images
^{99m}Tc	DTPA	Hydrophilic	BBB compromise	Planar	10-20 mCi	Immediate flow with 3-hour wait for images
^{99m}Tc	Glucaptate	Hydrophilic	BBB compromise	Planar	10-20 mCi	Immediate flow with 3-hour wait for images
^{123}I	IMP	Lipophilic	Passive diffusion	SPECT	2-3 mCi	20-60 min post injection
^{99m}Tc	HMPAO	Lipophilic	Passive diffusion	SPECT	20-30 mCi	20-60 min post injection
^{99m}Tc	ECD	Lipophilic	Passive diffusion	SPECT	10-20 mCi	30-60 min post injection
^{18}F	FDG	Metabolic	Perfusion and metabolism	PET	5-10 mCi	40 min

FDG has been found to demonstrate abnormal findings earlier than either CT or MRI.^{28,29} New techniques in MRI called functional MRI (fMRI) offer some advantages in stroke imaging, however, PET remains better for directly imaging metabolic processes.

CONCLUSION

Nuclear medicine modalities have been successful over a number of years in imaging and evaluating areas of the brain involved in stroke. Early imaging agents were hydrophilic in nature and relied upon crossing a compromised blood-brain barrier. Sensitivity of these agents varied with time. With the advent of CT and MRI imaging, these hydrophilic agents were no longer useful for stroke imaging. Modern lipophilic agents (^{99m}Tc -HMPAO and ^{99m}Tc -ECD) and metabolic agents (^{18}F -FDG) are more sensitive in the detection of stroke during the acute phase than are other imaging modalities. ^{99m}Tc -HMPAO, ^{99m}Tc -ECD, and ^{18}F -FDG are also useful for follow-up of patients who are in the subacute and later stages of stroke. PET has proven useful in the diagnosis and follow-up of stroke patients but obstacles have limited its wide use.

As technologies and procedures continue to advance, so too does healthcare's efforts to reduce the number of deaths

and the instances of disability that result from stroke.

REFERENCES

1. Heiss W, Podreka I. Cerebrovascular disease. In: Wagner H, Szabo Z, Buchanan J, eds. *Principles of Nuclear Medicine*. 2nd Ed. Philadelphia, Penn: WB Saunders Company; 1995: 531.
2. American Stroke Association Web site. Available at: <http://www.strokeassociation.org/STROKEORG/>. Accessed June 17, 2011.
3. Saha G. *Fundamentals of Nuclear Pharmacy*. 4th Ed. New York, NY: Springer; 1998: 240.
4. Burns H, Gibson R. Radiopharmaceuticals for cerebral imaging. In Henkin eds. *Nuclear Medicine*, Vol II. St. Louis, Missouri: Mosby; 1996: 1274.
5. Alexander G. Clinic diagnostic studies performed at the radioisotope laboratory, Cincinnati General Hospital. In: Simmons G. *A Training Manual for Nuclear Medicine Technologists*. Rockville, Maryland: US Department of Health, Education, and Welfare; 1970: 187.
6. Maynard C. *Clinic Nuclear Medicine*. Philadelphia, Penn: Lea & Febiger; 1971: 160.
7. Mettler F, Guiberteau M. *Essentials of Nuclear Medicine Imaging*. 3rd Ed. Philadelphia, Penn: WB Saunders Company; 1991: 60.
8. Bushnell D, Perlman S. Central nervous system. In: Wilson M, Ed. *Textbook of Nuclear Medicine*. Philadelphia, Penn: Lippincott-Raven; 1998: 241.

9. Saha G. Fundamentals of Nuclear Pharmacy. 4th ed. New York, NY: Springer; 1998: 240.
10. Yonekura Y, Fujita T, Nishizawa S, Iwasaki Y, Mukai T, Konishi J. Temporal changes in accumulation of N-isopropyl-p-iodoamphetamine in human brain: relation to lung clearance. *J Nucl Med.* 1989;30:1977-81.
11. Bushnell D, Perlman S. Central nervous system. In: Wilson M, Ed. *Textbook of Nuclear Medicine.* Philadelphia, Penn: Lippincott-Raven; 1998: 240.
12. Saha G. Fundamentals of Nuclear Pharmacy. 4th ed. New York, NY: Springer; 1998: 241.
13. Heiss W, Podreka I. Cerebrovascular disease. In: Wagner H, Szabo Z, Buchanan J, eds. *Principles of Nuclear Medicine.* 2nd ed. Philadelphia, Penn: WB Saunders Company; 1995: 535.
14. Moretti JL, Defer G, Cinotti L, et al. "Luxury perfusion" with ^{99m}Tc-HMPAO and ¹²³I-IMP SPECT imaging during the subacute phase of stroke. *Eur J Nucl Med.* 1990;16:17-22.
15. Saha G. Fundamentals of Nuclear Pharmacy. 4th ed. New York, NY: Springer; 1998: 242.
16. Spreafico G, Cammelli F, Gadola G, Freschi R, Zancaner F. Luxury perfusion syndrome in cerebral vascular disease evaluated with technetium-^{99m} HM-PAO. *Clin Nucl Med.* 1987;12:217-8.
17. Moretti JL, Tamgac F, Weinmann P, et al. Early and delayed brain SPECT with technetium-^{99m}-ECD and iodine-¹²³-IMP in subacute strokes. *J Nucl Med.* 1994;35:1444-9.
18. Miyazawa N, Koizumi K, Mitsuka S, Nukui H. Discrepancies in brain perfusion SPECT findings between Tc-^{99m} HMPAO and Tc-^{99m} ECD: evaluation using dynamic SPECT in patients with hyperemia. *Clin Nucl Med.* 1998;23:686-90.
19. Early P, Sodee D. Principles and Practices of Nuclear Medicine. 2nd Ed. St. Louis, Missouri: Mosby; 1995: 559-70.
20. Thrall J, Ziessman H. Nuclear Medicine: The Requisites. 2nd Ed. St. Louis, Missouri: Mosby; 2001: 309.
21. Bushnell D, Perlman S. Central nervous system. In: Wilson M, Ed. *Textbook of Nuclear Medicine.* Philadelphia, Penn: Lippincott-Raven; 1998: 242.
22. Thrall J, Ziessman H. Nuclear Medicine: The Requisites, 2nd Ed. St. Louis, Missouri: Mosby; 2001: 310.
23. Bushnell D, Perlman S. Central nervous system. In: Wilson M, Ed. *Textbook of Nuclear Medicine.* Philadelphia, Penn: Lippincott-Raven; 1998: 243.
24. Matsuda H, Li YM, Higashi S, et al. Comparative SPECT study of stroke using Tc-^{99m} ECD, I-¹²³ IMP, and Tc-^{99m} HMPAO. *Clin Nucl Med.* 1993;18:754-7.
25. Early P, Sodee D. Principles and Practices of Nuclear Medicine. 2nd Ed. St. Louis, Missouri: Mosby; 1995: 570.
26. Saha G. Fundamentals of Nuclear Pharmacy. 4th Ed. New York, NY: Springer; 1998: 243.
27. Mettler F, Guiberteau M. Essentials of Nuclear Medicine Imaging. 3rd Ed. Philadelphia, Penn: WB Saunders Company; 1991: 67.
28. Alavi J, Dann R, Chawluk J, Kushner M, Reivich M. Positron emission tomography imaging of regional cerebral glucose metabolism. *Semin Nucl Med.* 1986;16:2-34.
29. Jolles PR, Chapman PR, Alavi A. PET, CT, and MRI in the evaluation of neuropsychiatric disorders: current applications. *J Nucl Med.* 1989;30:1589-606.

NUCLEAR BRAIN IMAGING: STROKE POST TEST

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1. **Signs of stroke include all of the following EXCEPT**
 - a. bradycardia.
 - b. sudden numbness or weakness of the face.
 - c. sudden confusion.
 - d. difficulty seeing out of one or both eyes.
2. **The blood-brain barrier is an anatomical structure believed to be a combination of the following EXCEPT**
 - a. intracellular junction of endothelial cells in the cerebral capillaries.
 - b. lack of extracellular fluid space.
 - c. lack of pinocytosis.
 - d. CNS nerve endings.
3. **What were the first compounds developed for nuclear medicine imaging?**
 - a. Lipophilic compounds
 - b. Metabolic compounds
 - c. Synthetic compounds
 - d. Hydrophilic compounds
4. **^{99m}Tc pertechnetate hydrophilic compounds, pertechnetate was the first imaging agent used. What problems were encountered with this compound?**
 - a. Extremely expensive
 - b. Difficult to prepare
 - c. Slow renal clearance
 - d. Low background activity
5. **Using hydrophilic radiopharmaceuticals to detect stroke has many important factors. Which is the most essential?**
 - a. Time interval between the stroke and imaging
 - b. The size of the lesion
 - c. The position of the lesion
 - d. Low background activity
6. **^{99m}Tc-DTPA is principally used for which of the following?**
 - a. Renal imaging for metastatic disease
 - b. Estimations of glomerular filtration rates
 - c. Diagnosis and assessment of stroke
 - d. Thyroid imaging
7. **When injecting lipophilic imaging agents, it is important to**
 - a. maintain low lighting.
 - b. keep a steady noise in the background.
 - c. ensure that the patient's eyelids are closed.
 - d. play music to stimulate the brain.
8. **¹²³I-IMP requires two sets of image; the first should start between ___ and the second should be obtained ___ post injection.**
 - a. 2minutes; 20 minutes
 - b. 10 minutes; 1 hour
 - c. 10-15 minutes; 2 hours
 - d. 20-60 minutes; 3 hours

9. **Why must precautions be taken when administering ^{99m}Tc -HMPAO?**
- It is sensitive to oxidation.
 - Potential decomposition due to hydrophilic compounds may occur.
 - The phosphate buffer shortens shelf-life.
 - Lugol's solution must accompany it.
10. **Both ^{99m}Tc -HMPAO and ^{99m}Tc -ECD only require ___ set(s) of images for stroke imaging.**
- one
 - two
 - four
 - fifteen
11. **What types of collimators provide a good balance between sensitivity and resolution?**
- High energy
 - Low-energy
 - Low-energy, all-purpose
 - Fan-beam
12. **Playback and data manipulation results will display the images in all of the following projections EXCEPT**
- coronal.
 - curved.
 - transaxial.
 - sagittal.
13. **PET was slow to be adapted to mainstream due to which of the following reasons?**
- Insurers were reluctant to reimburse for its services.
 - Equipment is difficult to calibrate.
 - Unacceptably high radiation doses are given to patients.
 - It is rarely useful in the diagnosis of pathological conditions.
14. **Maximizing counts and resolution is difficult with lipophilic agents because**
- patients may not be able to tolerate the procedure.
 - metabolic compounds are better suited for counts and resolution.
 - physicians prefer a 61 x 64 matrix set.
 - manipulation and playback are largely unavailable when using these agents.
15. **Comparing nuclear medicine brain imaging to CT, when exams are performed within the first 8 hours of onset,**
- defects on SPECT are typically smaller than those seen on CT.
 - defects are not seen with either modality until 24 hours after symptom onset.
 - CT is dramatically more sensitive than nuclear medicine brain imaging.
 - nuclear medicine brain imaging is dramatically more sensitive than CT.
16. **The development of ^{18}F -FDG was linked to**
- its short half-life compared to other cyclotron-produced PET radionucleotides.
 - the observation that only cancer cells metabolize it.
 - the observation that viable brain cells will transport glucose from the circulation for use as an energy source.
 - the transitory nature of PET radionucleotides.
17. **After ^{18}F -FDG is administered intravenously, images may be obtained ____ later.**
- 5 minutes
 - 40 minutes
 - 6 hours
 - 12 hours
18. **Which of these has been found to demonstrate stent findings earliest in stroke imaging cases?**
- CT
 - MRI
 - FDG
 - Ultrasound
19. **Which of these is most practical for directly imaging metabolic processes?**
- CTA
 - MRA
 - FDG
 - Ultrasound
20. **Early hydrophilic agents relied on**
- scanning patients in the subacute and later stages of stroke.
 - an intact blood-brain barrier.
 - increased glucose metabolism of the damaged brain.
 - crossing a compromised blood-brain barrier.



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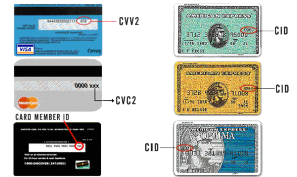
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3. a b c d	8. a b c d	13. a b c d	18. a b c d
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