the volume of the human gallbladder. *Radiology* 1949;52:94–102.
11. Everson GT, Braverman DZ, Johnson MA, Kern E Jr. A critical evaluation of real time ultrasonography for the study of gallbladder volume and contraction. *Gastroenterology* 1980;79:40–46.
12. Admirand WH, Small DM. Physiochemical basis of cholesterol gallstone formation in men. *J Clin Invest* 1968;47:1043–1052.
13. Rose JD. Serial cholecystography: a means of pre-operative diagnosis of biliary dyskinesia. *Arch Surg* 1959;78:56–66.
14. Masclee AM, Hopman WPM, Corstens FHM, et al. Simultaneous measurement of gallbladder emptying with cholescintigraphy and ultrasound during infusion of physiologic doses of cholecystokinin: a comparison. *Radiology* 1989;173:407–410.
15. Ivy AC, Oldberg EA. A hormone mechanism for gallbladder contraction and evacuation. *Am J Physiol* 1928;86:599–613.
16. Krishnamurthy GT, Bobba Vr, Kingston E, Turner FE. Measurement of gallbladder emptying sequentially using a single dose of a Tc-99m-labeled hepatobiliary agent. *Gastroenterology* 1982;83:773–777.
17. Mesgardeh M, Krishnamurthy GT, Bobba VR, Langrell K. Filling post-cholecystokinin emptying and refilling of normal gallbladder: effect of two different doses of CCK on refilling: concise communication. *J Nucl Med* 1983;24:166–671.
18. Sturdevant RA, Stern DH, Resin H, Eisenberg JI. Effect of graded doses of octapeptide of cholecystokinin on gallbladder size in man. *Gastroenterology* 1973;64:452–456.
19. Krishnamurthy GT, Bobba VR, Kingston E. Optimization of octapeptide of cholecystokinin (OP-CCK) dose for gallbladder emptying. In: Raynaud C, ed. *Proceedings of the third world congress of nuclear medicine and biology.* Paris: France: Pergamon Press; 1982:2244–2247.
20. Ziessman HA, Fahey FH, Hixson DJ. Calculation of a gallbladder ejection fraction: advantage of continuous Sincalide infusion over the 3-min infusion method. *J Nucl Med* 1992;33:537–541.
21. Courtney DF, Clanachan AS, Scott GW. Cholecystokinin constricts the canine cystic duct. *Gastroenterology* 1983;85:1154–1159.

SELF-STUDY TEST

Pulmonary Nuclear Medicine

Questions are taken from the *Nuclear Medicine Self-Study Program I*, published by The Society of Nuclear Medicine

DIRECTIONS

The following items consist of a question followed by five lettered answers. Select the one lettered answer that is best in each case. Answers may be found on page 580.

1. The ^{81m}Kr ventilation and ^{99m}Tc MAA perfusion images shown in Figure 1 were obtained from a 23-yr-old man with shortness of breath. Which *one* of the following is the most likely diagnosis?

A. bronchial adenoma
B. pulmonary embolism
C. fibrosing mediastinitis
D. asthma
E. Swyer-James syndrome

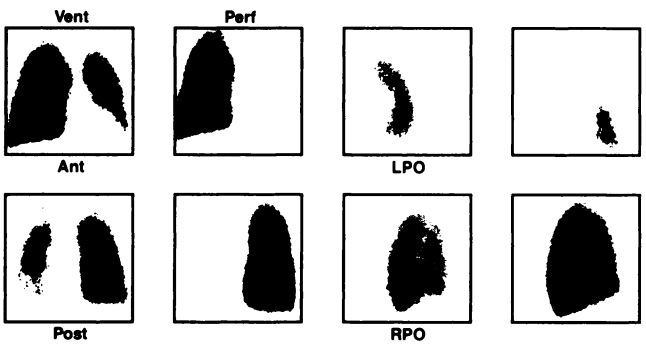

Figure 1

2. The same patient underwent a repeat ventilation–perfusion study (Fig. 2) 10 days later. Considering both of this patient's studies, which *one* of the following is the most likely diagnosis?

A. emphysema
B. anxiety reaction
C. pneumonia
D. asthma
E. pulmonary embolism

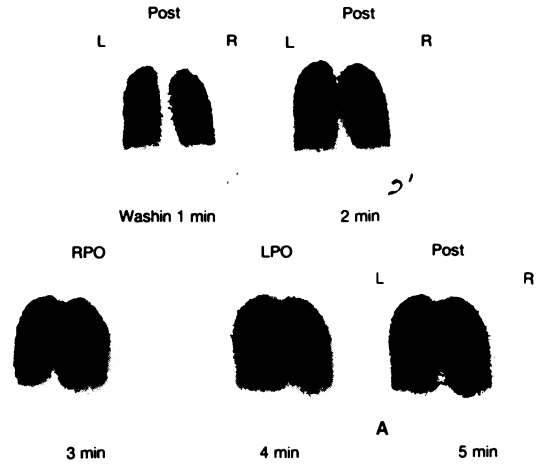

Figure 2A

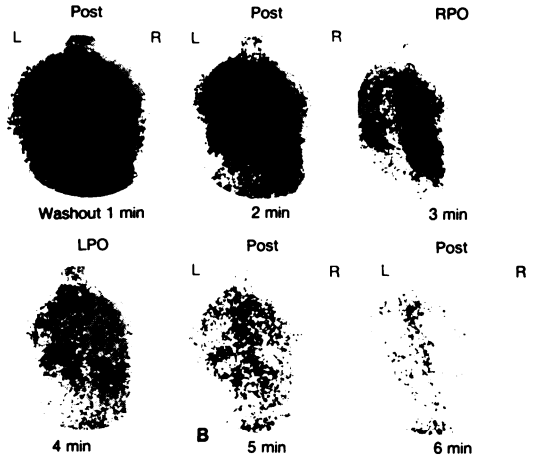

Figure 2B

(continued on p. 569)

21. Hiskey RG, Tomishige M, Igeta H. Sulfur-containing polypeptides. II. Selective removal of S-protective groups from some L-cysteinyl-L-cysteine derivatives. *J Org Chem* 1966;31:1188–1192.
22. Brenner D, Davison A, Lister-James J, Jones A. Synthesis and characterization of a series of isomeric oxotechnetium(V) diamido dithiolates. *Inorg Chem* 1984;23:3793–3797.
23. Mahmood A, Baidoo KE, Lever SZ. Stereoisomers of neutral oxotechnetium(V) and oxorhenium(V) complexes. In: Nicolini M, Bandoli G, Mazzi U, eds. *Technetium and rhenium in chemistry and nuclear medicine, volume 3.* New York: Raven Press; 1990:119–124.
24. Ojasoo T, Dore J-C, Gilbert J, Raynaud J-P. Binding of steroids to the progestin and glucocorticoid receptors analyzed by correspondence analysis. *J Med Chem* 1988;31:1160–1169.
25. Pomper MG, Katzenellenbogen JA, Welch MJ, Brodack JW, Mathias CJ. 21-[^{18}F]Fluoro-16α-ethyl-19-norprogesterone: synthesis and target tissue selective uptake of a progestin receptor based radiotracer for positron emisson tomography. *J Med Chem* 1988;31:1360–1363.
26. Deutsch E, Libson K, Vanderheyden J-L, Ketring AR, Maxon HR. The chemistry of rhenium and technetium as related to the use of isotopes of these elements in therapeutic and diagnostic nuclear medicine. *Nucl Med Biol* 1986;13:465–477.
27. Deutsch E, Libson L, Vanderheyden JL. The inorganic chemistry of technetium and rhenium as relevant to nuclear medicine. In: Nicolini M, Bandoli G, Mazzi U, eds. *Technetium and rhenium in chemistry and nuclear medicine, volume 3.* New York: Raven Press; 1990:13–22.
28. Katzenellenbogen JA, Heiman DF, Carlson KE, Lloyd JE. In vivo and in vitro steroid receptor assays in the design of estrogen radiopharmaceuticals. In: Eckelman WC, ed. *Receptor binding radiotracers, volume 1.* Boca Raton, FL: Chemical Rubber Co., 1982:93–126.
29. Keightley DD. The binding of progesterone, R-5020 and ORG-2058 to progesterone receptor. *Eur J Cancer* 1979;15:785–790.
30. Manz B, Grill H-J, Pollow K. Steroid side-chain modification and receptor affinity: binding of synthetic derivatives of corticoids to human spleen tumor and rat liver glucocorticoid receptors. *J Steroid Biochem* 1982;17:335–342.
31. Sheppard KE, Funder JW. Equivalent affinity of aldosterone and corticosterone for type I receptors in kidney and hippocampus: direct binding studies. *J Steroid Biochem* 1987;28:737–742.
32. Pomper MG. Fluorine-18 labeled estrogens, progestins and corticosteroids for receptor-based imaging of breast tumors and target areas of the brain. PhD thesis. University of Illinois, 1989.
33. Swinscow TDV. The t-tests. In: *Statistics at square one.* Bath, England: Mendip Press; 1980:33–42.

(continued from p. 544)

SELF-STUDY TEST

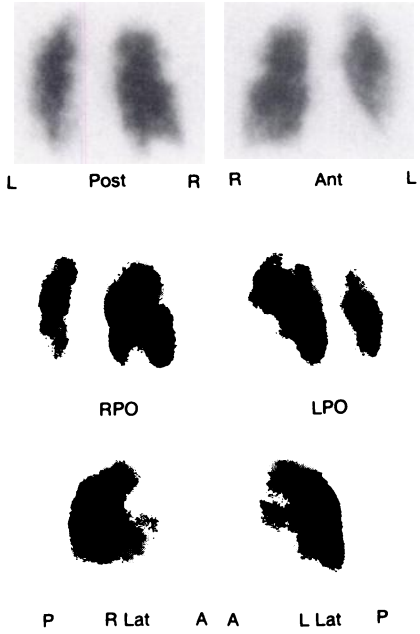

Figure 2C

3. A 45-yr-old white housewife with a 40 pack-year smoking history presents with progressive shortness of breath and an 8-pound weight loss. She denies febrile episodes, frequent respiratory infections, or excessive sputum production, but she has a dry cough. Her husband is bisexual. Clinical and laboratory examinations reveal cervical and inguinal lymphadenopathy and liver function abnormalities. Her ^{67}Ga scintigram is shown in Figure 3. Which *one* of the following is the most likely diagnosis?

A. bronchogenic carcinoma with lymph node metastases
B. Hodgkin's lymphoma
C. acquired immunodeficiency syndrome with *Pneumocystis carinii* pneumonia
D. sarcoidosis
E. hypersensitivity pneumonitis

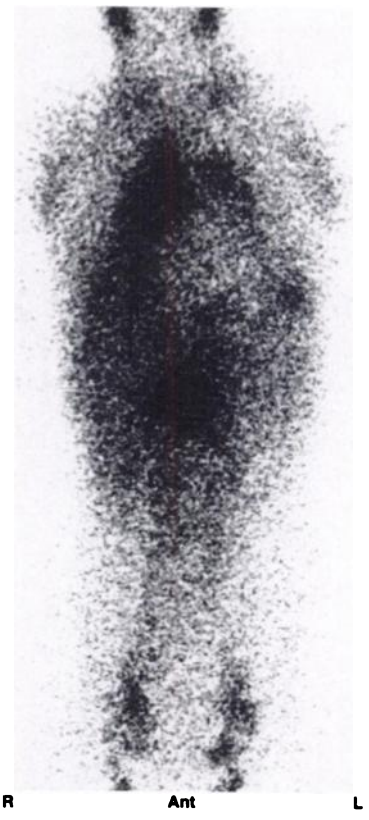

Figure 3

4. Which *one* of the following properties of a radioaerosol is *least* important in determining its rate of clearance from the lung?

A. solubility
B. lipophilicity
C. droplet size
D. pulmonary blood flow rate
E. alveolar–capillary membrane permeability

(continued on p. 580)

remote myocardial infarction in patients with positron emission transaxial tomography and intravenous C-11-palmitate. *Circulation* 1977;55:853–857.
6. Ratib O, Phelps ME, Huang SC, Henze E, Selin CE, Schelbert HR. Positron tomography with deoxyglucose for estimating local myocardial glucose metabolism. *J Nucl Med* 1982;23:577–586.
7. Pike VW, Eakins MN, Allan RM, Selwyn AP. Preparation of [1-^{11}C] acetate—an agent for the study of myocardial metabolism by positron emission tomography. *Int J Appl Radiat Isot* 1982;33:505–512.
8. Martin GV, Caldwell JH, Grunbaum Z, Cerqueira M, Krohn KA. Enhanced binding of the hypoxic cell marker [^{18}F]misonidazole in ischemic myocardium. *J Nucl Med* 1989;30:194–201.
9. Shelton ME, Dence CS, Hwang D-R, Welch MJ, Bergmann SR. Myocardial kinetics of fluorine-18-misonidazole: a marker of hypoxic myocardium. *J Nucl Med* 1989;30:351–358.
10. Khaw BA, Gold HK, Leinbach RC, et al. Early imaging of experimental myocardial infarction by intracoronary administration of I-131-labeled anticardiac myosin F(ab')$_2$ fragments. *Circulation* 1978;58:1137–1142.
11. Khaw BA, Mattis JA, Melincoff G, et al. Monoclonal antibody to cardiac myosin; scintigraphic imaging of experimental myocardial infarction. *Hybridoma* 1984;3:11–23.
12. Khaw BA, Fallon JT, Strauss HW, et al. Myocardial infarct imaging of antibodies to canine cardiac myosin with indium-111-diethylenetriamine pentaacetic acid. *Science* 1980;209:295–297.
13. Khaw BH, Yasuda T, Gold HK, et al. Acute myocardial infarct imaging with indium-111-labeled monoclonal antimyosin Fab. *J Nucl Med* 1987;28:1671–1678.
14. Volpini M, Giubbini F, Gei P, et al. Diagnosis of acute myocardial infarction by indium-111 antimyosin antibodies and correlation with the traditional techniques for the evaluation of extent and localization. *Am J Cardiol* 1989;63:7–13.
15. Nishimura T, Sada M, Sasaki H, et al. Identification of cardiac rejection in heterotopic heart transplantation using ^{111}In-antimyosin. *Eur J Nucl Med* 1987;13:343–347.
16. Yasuda T, Palacios IF, Dec GW, et al. Indium-111 monoclonal antimyosin antibody imaging in the diagnosis of acute myocarditis. *Circulation* 1987;76:306–311.
17. Garg PK, Garg S, Zalutsky MR. Fluorine-18 labeling of monoclonal antibodies and fragments with preservation of immunoreactivity. *Bioconjugate Chem* 1991;2:44–49.
18. Khaw BA, Gold HK, Yasuda T, et al. Scintigraphic quantification of myocardial necrosis in patients after intravenous injection of myosin-specific antibody. *Circulation* 1986;74:501–508.
19. Hoberg E, Eisenhut M, Hofmann M, et al. Monoclonal antibodies specific for human cardiac myosin: selection, characterization and experimental myocardial infarct imaging. *Eur Heart J* 1988;9:328–336.
20. Goethals P, Coene M, Slegers G, et al. Production of carrier-free ^{66}Ga and labeling of antimyosin antibody for positron imaging of acute myocardial infarction. *Eur J Nucl Med* 1990;16:237–240.
21. Khaw BA, Beller GA, Haber E, Smith T. Localization of cardiac antimyosin antibody in myocardial infarction. *J Clin Invest* 1976;58:439–446.
22. Nedelman MA, Shealy D, Boutin R, et al. Rapid infarct imaging with a new Tc-99m antimyosin sFv fragment: evaluation in acute myocardial infarction in dogs [Abstract]. *J Nucl Med* 1991;32:1005.

(continued from p. 569)

SELF-STUDY TEST
Pulmonary Nuclear Medicine
ANSWERS

ITEM 1: Entire Lung Ventilation-Perfusion Mismatch

ANSWER: C

The perfusion images in Figure 1 show almost complete absence of perfusion to the left lung and normal perfusion of the right lung. The ^{81m}Kr ventilation images show only mild impairment of ventilation of the left lung.

Fibrosing mediastinitis, whether idiopathic or secondary to granulomatous infections (typically tuberculosis or histoplasmosis), can lead to central vascular obstruction. In turn, this can produce unilaterally reduced or absent pulmonary perfusion, although obstruction of the superior vena cava is a much more common complication. The bronchi are more resistant to extrinsic compression than are the pulmonary vessels because of their rigid cartilaginous rings. Hence, perfusion is more severely impaired than ventilation in most cases where there is mediastinal fibrosis or mass.

Pulmonary embolism is not likely in this case. Because emboli are usually multiple and bilateral, it would be unusual to observe a massive embolus entirely occluding flow to one lung without detecting any perfusion deficit in the other lung.

Both bronchial adenoma and Swyer-James syndrome would be expected to cause more severe impairment of ventilation than of perfusion in the affected lung. The same would also be true of the regional (segmental) abnormalities seen with asthma; further, unilateral involvement with asthma would be highly unlikely.

Reference

1. Kim EE, DeLand FH. V̇/Q̇ mismatch without pulmonary emboli in children with histoplasmosis. *Clin Nucl Med* 1978;3:328–330.

ITEM 2: Pulmonary Embolism with Bronchoconstriction

ANSWER: E

The repeat study 10 days later (Fig. 2) shows almost complete resolution of the ventilatory abnormalities with significant, but lesser, improvement in the perfusion defects. Thus, pulmonary embolism (with early, acute bronchoconstriction at the time of initial study) is the most likely diagnosis. Bronchospasm due to asthma could have explained the initial findings, but not the persisting perfusion defects at 10 days, when ventilation had returned to normal. Ventilatory abnormality due to emphysema would not have resolved to the extent seen in this patient. There is no evidence to suggest pneumonia, and the scintigraphic abnormalities make anxiety reaction an untenable explanation.

The patient did, in fact, undergo angiography after the first study, and multiple emboli were found. Acute bronchoconstriction due to pulmonary embolism and of sufficient magnitude to cause distinct abnormalities on ventilation imaging is uncommon, but should be considered when multiple segmental perfusion defects are seen and not readily explained by known airways disease.

Reference

1. Kessler RM, McNeil BJ. Impaired ventilation in a patient with angiographically demonstrated pulmonary emboli. *Radiology* 1975; 114:111–112.

ITEM 3 Sarcoidosis

ANSWER: D

The gallium image shown in Figure 3 demonstrates increased uptake of tracer in the lungs and parotid regions. There is also a symmetrical pattern of nodal disease involving the cervical, supraclavicular, hilar, paraaortic, inguinal, and femoral nodes. Bronchogenic carcinoma with lymph node involvement may show pulmonary and mediastinal uptake of ^{67}Ga, as well as gallium localization in distant metastases. However, the symmetry of involvement would be highly unlikely for metastatic disease. Lymphoma is a good possibility, given this patient's history, except that patients with Hodgkin's disease often present with intermittent fever or night sweats. Although gallium uptake in nodal chains and in the lungs is consistent with lymphoma, the high degree of symmetry and the parotid involvement make this diagnostic possibility less likely than sarcoidosis, which is the best fit to the clinical and scintigraphic findings. The pattern of gallium uptake with hypersensitivity pneumonitis or with *Pneumocystis carinii* pneumonia in patients with AIDS rarely includes tracer uptake in the lymph nodes. Generally, there is diffuse pulmonary uptake of moderate to high intensity with *P. carinii* pneumonia and of low to moderate intensity in hypersensitivity pneumonitis. In patients with AIDS, hilar and mediastinal nodal ^{67}Ga uptake may be seen with

(continued on p. 612)

1990;37:642–646.
24. Rosenthal MS, Henry LJ. Scattering in uniform media. *Phys Med Biol* 1990;35:265–274.
25. Manglos SH, Floyd CE, Jaszczak RJ, Greer KC, Harris CC, Coleman RE. Experimentally measured scatter fractions and energy spectra as a test of Monte Carlo simulations. *Phys Med Biol* 1987;22:335–343.
26. Press WH, Flannery BP, Teukolsky SA, Vetterling WT. *Numerical recipes: the art of scientific computing.* New York: Cambridge A.P.; 1986:521–528.
27. Sorenson JA, Phelps ME. *Physics in nuclear medicine,* second edition. Orlando: Grune and Stratton; 1987:372–375.
28. Gonzalez RC, Wintz P. *Digital image processing.* Reading: Addison-Wesley; 1977:145–148.
29. Bellini S, Piacentini M, Cafforio C. Compensation of tissue absorption in emission tomography. *IEEE Trans Acous Speech Sig Proc* 1979;27:213–218.
30. Glick SJ, Hawkins WG, King MA, Penney BC, Soares EJ, Byrne C. Choice of intrinsic attenuation correction method and the three-dimensional modulation transfer function of SPECT. *Med Phys* 1992: in press.
31. King MA, Glick SJ, Penney BC. Activity quantitation in SPECT: a comparison of three attenuation correction methods in combination with pre-reconstruction restoration filtering. *IEEE Trans Nucl Sci* 1991;38:755–760.
32. Rogers WL, Clinthorne NH, Harkness BA, Koral KF, Keyes JW. Field-flood requirements for emission computed tomography with an Auger camera. *J Nucl Med* 1982;23:166–168.
33. Swailem FM, Koral KF, Rogers WL. Count-based monitoring of Anger-camera spectra-local energy shifts due to rotation. *Med Phys* 1991;18:565–567.
34. Ljungberg M, Strand SE. A Monte Carlo program for the simulation of scintillation camera characteristics. *Comput Meth Progr Biomed* 1989;29:257–272.
35. Hademenos GJ, Ljungberg M, King MA, Glick SJ. A Monte Carlo investigation of the dual photopeak window scatter correction method. *IEEE Trans Nucl Sci* 1992: submitted.

(continued from p. 580)

SELF-STUDY TEST
Pulmonary Nuclear Medicine
ANSWERS

secondary lymphoma or with infection due to *Mycobacterium tuberculosis* or *Mycobacterium avium-intracellulare*. Gallium accumulation associated with the lymphadenopathy of AIDS per se is usually of relatively mild intensity.

ITEM 4 Pulmonary Clearance of Radioaerosols

ANSWER: D

Numerous factors are important in determining the clearance rate of a radioaerosol from the lung. Major differences exist between the clearance rates and pathways of soluble and insoluble aerosols. Insoluble aerosols include those of particulate nature, such as ^{99m}Tc colloids or albumin particles, which must be cleared from the airways and alveoli by either mucociliary action or by lymphatic drainage. Mucociliary clearance requires several hours, even from relatively central airways, and lymphatic clearance of particulates can take days to weeks. On the other hand, soluble radioaerosols are cleared quickly by gaining direct access to the pulmonary blood supply across the alveolar-capillary membrane.

The clearance rates of various soluble aerosols are influenced by a number of factors, including the lipophilicity and polarity of the agent. In general, the more lipophilic and polar compounds are likely to be absorbed more rapidly. The molecular weight of a compound, however, also seems to have an influence. Some relatively high molecular weight lipophilic compounds have slower pulmonary clearances than would be predicted from their lipid solubility alone.

Size is an important factor in radioaerosol clearance, whether the size refers to the molecular weight of a soluble compound, as mentioned above, or whether it refers to the physical size of the inhaled aerosol droplets. Larger aerosol droplets tend to deposit more centrally. From this central location, mucociliary clearance can act more effectively and quickly to clear the particles from the lungs. Conversely, if molecular size is considered, a larger compound may have a slower peripheral clearance. An agent with a combination of physical characteristics leading to the fastest clearance would have a relatively small molecular weight and be a polar, lipophilic compound delivered to the lung as a submicronic aerosol.

Alveolar-capillary membrane permeability appears to be a major factor in determining the clearance rate of soluble radioaerosols from the lung. The clearance of these compounds seems to be related far more closely to the available surface area for absorption across this membrane than to the pulmonary blood flow rate, itself. Total obstruction of pulmonary arterial flow to a lung leads to markedly diminished clearance of soluble radioaerosols, although a small amount of radioaerosol activity still may be absorbed through the bronchial circulation. However, within the typical range of pulmonary blood flow rates encountered in clinical practice, blood flow rate per se has relatively little influence on clearance rates.

For further in-depth information, refer to the syllabus pages in Nuclear Medicine Self-Study I.