Cardiovascular Nuclear Medicine Training Guidelines

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The Credentialing Subcommittee of the Cardiovascular Council of the Society of Nuclear Medicine has formulated the following *Cardiovascular Nuclear Medicine Training Guidelines*, which are a modification and update of similar guidelines set forth in 1989 by the Education and Training Committee of the Society of Nuclear Medicine. The Subcommittee is composed of cardiologists, nuclear medicine physicians and basic scientists who are leaders in the field of cardiovascular nuclear medicine and who have been intimately involved in resident and fellow education. These individuals were selected so that diverse viewpoints and practice patterns in cardiovascular nuclear medicine would be represented. The Credentialing Subcommittee has worked with the present Chairman of the Education and Training Committee in formulating these guidelines in order that the standards and goals of both bodies are promulgated.

These guidelines are meant to serve as a template for didactic material (Part I) and laboratory practicum exercises (Part II) for all training programs in cardiovascular nuclear medicine, whether they are part of a nuclear medicine, radiology or cardiology residency or fellowship. The didactic portion should be covered in lectures, which may be supplemented by a structured review of reading assignments or conferences, depending upon the individual training program. The Subcommittee strongly recommends that trainees be periodically evaluated regarding their comprehension of the topics listed. Similarly, practicum assignment write-ups should be evaluated regularly by a faculty member.

Certain topics listed in the guidelines may be redundant, depending upon the parent training program. For instance, cardiac anatomy and physiology most likely will have been covered in sufficient depth in a cardiology fellowship to allow omission in a subsequent nuclear cardiology fellowship. Similarly, the basics of radiation detection will probably be well known to radiologists and nuclear medicine physicians. Therefore, a program's adherence to the guidelines should be considered by review of both the cardiovascular nuclear medicine traineeship and the antecedent didactic curriculum of the nuclear medicine, cardiology or radiology residency/fellowship, when applicable.

In Part III of the guidelines, the Subcommittee has offered recommendations regarding the requirements of institutions sponsoring cardiovascular nuclear medicine training programs. Also, recommendations are made with regard to the minimum number of clinical imaging studies and exposure to correlative modalities.

PART I: DIDACTIC LECTURE AND READING TOPICS

* An asterisk indicates topics we believe should be mentioned and defined so that trainees are familiar with them, but which need not be covered in the detail required for practical, working knowledge.

PHYSICS AND INSTRUMENTATION

I. Essential Preliminaries

A. The structure of matter as a preliminary to radiation sources and radiation interactions
   1. Energy, nature and definitions; fundamental particles
   2. Structure of the atom, nucleus and electrons
   3. Structure of the nucleus, protons and neutrons

B. Nature of radiation

Editor's Note: Adopted from the *Guidelines for Topics for Training of Radiology Residents and Cardiology Fellows in Nuclear Medicine* formulated by the Education and Training Committee of the Society of Nuclear Medicine, October 1, 1989.

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1. Charged particles (electrons, positrons, protons and alpha particles)
2. Electromagnetic radiation (photons)
   a. Wave and particle nature of photons
   b. Classification by energy: infrared, light, ultraviolet, x-rays, gamma rays and radio waves
3. Neutral particles: nature, characteristics

C. Interaction of radiation with matter
1. Charged particle interactions with matter are the chief means of energy transfer to matter
   a. Atomic excitation, ionization
   b. Bremsstrahlung generation
   c. Annihilation of positrons
   d. Energy-range relationships
2. Photon interactions
   a. Photoelectric absorption: usefulness in detection and shielding
   b. Compton scattering is the primary fate of photons in tissue
   c. Other (pair production, coherent scattering)
   d. Energy-range relationships
3. The role of neutrons in production of artificial radioactivity
   a. Inelastic nuclear collisions, nuclear reactions, capture
   b. Energy-range relationships

II. Radioactivity

A. Nuclear de-excitation is the chief source of photons for imaging
1. Isomeric transitions
   a. Gamma photons
   b. Internal conversion
2. Antecedent states to isomeric transitions
   a. De-excitation of neutron-rich nuclei
   b. De-excitation of neutron-poor nuclei
3. Atomic sequelae to nuclear de-excitation
   a. Characteristic x-rays
   b. Auger transitions
4. Mathematics of nuclear de-excitation
   a. Characteristics of exponential functions
   b. Radioactive equilibrium

B. Production of radionuclides: methods which affect availability and cost
1. Fission reactors
   a. Neutron irradiation
   b. Fission products
2. Charged-particle accelerators
3. Radionuclide generators
   a. Types
   b. Practical aspects
   c. Economics

III. Mathematics and Statistics

A. Randomness
1. Radioactive decay
2. Practical consequences of random events
3. Exponential functions resulting from random group behavior

B. Precision and accuracy
1. Bias
2. Determinate and indeterminate errors

C. Frequency distributions
1. Poisson and Gaussian distributions
2. Measures of dispersion: standard deviations, confidence intervals and Chi-squared estimates

D. Statistics of radioactivity detection and measurement
1. Standard deviation of count data
2. Compounding of indeterminate errors: calculation of error, subtraction of background counts
3. Image statistics
   a. Tests for significance in test images (floods, etc.)
   b. Tests for significance in clinical images

E. Applied statistical methods
1. Determination of separateness of distributed populations
2. Mathematics of decision making

*F. Linear regression

*G. Stepwise multivariate regression analysis

IV. Radiation Effects, Absorbed Dose

A. Biological effects of radiation
1. The Roentgen is a unit of radiation *exposure*
2. Rads and rems (Grays and Sieverts) are units of *absorbed dose*
3. Biological effects of radiation
   a. Chemical effects of energy deposition
   b. Molecular and cell effects
   c. Cellular, tissue and organ sensitivity
   d. Quality factor, RBE and LET
4. Risks of radiation exposure

B. Decay of radioactivity in the body
1. Physical half-life
2. Biological half-life
3. Effective half-life

C. Absorbed radiation dose estimation
1. "Absorbed fraction"—(MIRD) method
2. Critical organ, whole-body doses
3. Radiation dose equivalents

V. Instrumentation

A. Basic principles
1. Gas-filled radiation detectors, though old, used in many forms
   a. Ionization chambers, portable and in dose calibrators
   b. Geiger-Mueller counters are "event counters"
2. Scintillation detectors
   a. Organic, liquid scintillators

b. Inorganic scintillators are used in nuclear medicine
3. Solid-state detectors
4. Electronics of energy-proportional systems
a. Photomultiplier tubes, solid-state detectors and wiring
b. Charge collection, pulse-shaping (preamp/amp)
c. Energy discrimination, "windows"
d. Data recording and display
5. Nature of the NaI(Tl) pulse-height spectrum
a. The "total absorption (photo) peak" is the useful feature
b. The "Compton continuum" is not useful, but present
c. Coincidence summing and escape phenomena complicate things

B. Support and ancillary instrumentation
1. Radiation detector systems
a. Well scintillation detectors, quality control
b. Detectors for radionuclidic purity checks (GeLi)
c. Survey meters are required under license terms
d. Dose calibrators and their quality control
2. Other
a. Electrocardiographs, R-wave triggers
1. Frame versus list node
2. Arrhythmia rejection mechanisms
3. Gated SPECT
b. Respirators
c. Exercise equipment
d. Motion correction mechanisms

C. Imaging instrumentation
1. Gamma (Anger) cameras
a. Basics (and limitations) of the image-formation process
b. Detectors, collimation and effects of distance on resolution
c. Position information generation and normalization
d. Energy discrimination, proper "peaking"
e. Operating characteristics (field of view, resolution, sensitivity, counting losses, NEMA specifications)
f. Artifacts, effects of pre-detector scatter
g. Quality control
h. Environmental hazards
2. Multicrystal cameras
3. Other planar imaging systems
4. Single-photon emission computed tomography (SPECT)
a. Reconstructive methods, spatial and temporal filters
b. Artifacts, attenuation and scatter correction
c. System management
d. Quality assurance
e. Single-head versus multihead detector systems
5. Positron emission tomography (PET)

D. Photographic imaging and image-making devices
1. Photographic fundamentals
a. Optical image generation
b. Film construction and the latent image
c. Film processing
2. Film characteristics
a. Density versus exposure
b. Speed
c. Effects of processing
3. CRT and video image devices
a. Basic operation
b. Evidence of irreparable deterioration
c. Quality control

E. Computer architecture
a. Central processing unit (CPU)
b. Bus structure, basic I/O
c. Terminal equipment
d. Magnetic storage devices
2. Software concepts
a. Numerical methods
b. The operating system
c. User programming languages
3. Image digitization, storage and manipulation
a. Effects on image content and on image appearance, artifacts
b. Limitation on processing speed
4. System connection to gamma cameras
a. Position, strobe signals
b. R-wave trigger for gated heart blood pool studies
5. System operation
a. System start-up (boot), shut down
b. Printing, archiving operations
c. Gamma camera data acquisition
d. Image manipulation, ROI and curve operations
e. Nuclear medicine procedures, data acquisition and analysis
f. Quality assurance

F. Instrumentation and technique in each clinical procedure
1. Use of the instrument (gamma camera)
a. Selecting the right collimator(s)
b. Use of the computer
c. Set energy windows to appropriate photopeak(s) for radionuclide in procedure
2. Technique
a. Positioning
b. Timing of imaging (early, late, next day)
c. Required and optional views

d. Marking for anatomy, pathology and image orientation

RADIOPHARMACEUTICALS

I. Radionuclide Considerations
- A. Characteristics of the ideal radionuclide for:
  1. Diagnostic imaging
  2. Therapeutic applications
- B. Radionuclides
  1. Methods of production
  2. Decay considerations
  3. Purity, specific activity considerations

II. Technetium-99m Physics and Chemistry
- A. Radionuclide properties
  1. Mode of decay
  2. Radiation emissions
  3. Interaction of gamma emissions with tissue, sodium iodide, lead
  4. Half-life considerations
- B. Chemistry
  1. Valence states, reduction
  2. Chelation, ligand chemistry
  3. "Kit" descriptions and uses
- C. Molybdendum-99m—Technetium-99m generator
  1. Principles
     a. Parent-daughter relationships
     b. Transient equilibrium
  2. Description
     a. Internal construction
     b. Wet column versus dry column
  3. Characteristics
     a. Elution profiles
     b. Multiple elution considerations
     c. Calibration considerations

III. Chemistry of Other Radionuclides
- A. Iodine-131 and Iodine-123
- B. Gallium-67
- C. Indium-111
- D. Thallium-201
- E. Xenon-133 and Xenon-127
- F. Short-lived tracers for first pass radionuclide angiocardiography
  1. Iridium-191
  2. Tantalum-182
  3. Gold-195m
- G. PET radiopharmaceuticals
  1. Fluorine-18-fluorodeoxyglucose
  2. Oxygen-15-water
  3. Nitrogen-13-ammonia
  4. Carbon-11-palmitate
  5. Rubidium-82

IV. Cell Labeling
- A. Red blood cells
- B. White blood cells
- C. Potential hazards of radiopharmaceutical misadministration

V. Quality Control
- A. Record-keeping system
  1. Desired features
  2. Regulatory requirements (NRC, JCAHO, FDA, USP, pharmacy boards)
- B. Radiochemical purity
  1. Definition and sources
  2. Potential radiochemical impurities in ^{99m}Tc radiopharmaceuticals
  3. Evaluation methods
     a. Types of radiochromatography
     b. Solvent/support systems to evaluate ^{99m}Tc radiochemical impurities
     c. Quantification of test results
  4. Practical limits: clinical considerations
- C. Radionuclidic purity
  1. Definition and sources
  2. Potential radionuclide impurities in ^{99m}Tc generator eluates
  3. Evaluation methods
     a. Differential shielding techniques
     b. Multichannel analysis
  4. NRC/FDA limits: clinical considerations
- D. pH testing: method, clinical considerations
- E. Aluminum ion breakthrough testing: method, clinical considerations no breakthrough
- F. Molybdendum-99 breakthrough testing
- G. Particle sizing: method, clinical considerations
- H. Sterility/pyrogen testing
  1. Definitions and methods
  2. Sources of contamination; aseptic techniques

VI. Radiopharmaceuticals in Each Clinical Procedure (including ^{111}In-antimyosin and ^{99m}Tc-labeled radiopharmaceuticals for perfusion imaging)
- A. Radiopharmaceutical characteristics
  1. Physical and chemical properties pertinent to each procedure
  2. Mechanisms of normal and abnormal localization
  3. Standard doses
  4. Radiation dosimetry (body, critical organs and significant radiation doses
  5. Advantages/disadvantages of:
     a. Previous agents
     b. Current agents
- B. Radiopharmaceutical formulation problems
  1. Chemical/physical considerations
  2. Clinical implications
- C. Radiopharmaceutical-drug interactions
  1. Mechanisms of interaction
  2. Clinical implications/altered biodistribution
- D. Adjunctive drugs/procedures
  1. Dose, timing
  2. Adverse reactions, contraindications
- E. Interventional drugs/procedures
  1. Mechanism of action/study enhancement

2. Dose, timing
3. Adverse reactions, contraindications

VII. Pharmacologic Substitutes to Dynamic Exercise

A. Coronary vasodilators
1. Dipyridamole
2. Adenosine

B. Positive inotropic/chronotropic agents
1. Dobutamine
2. Arbutamine

RADIATION SAFETY

I. Knowledge Required for Licensure

A. Philosophy of radiation protection
1. Linear, no-threshold dose-effect relationship
2. Maximum permissible dose
3. ALARA

B. Sources of radiation exposure

C. Facility purpose and design

D. Radiation monitoring
1. Personnel
2. Facility
3. Environmental
4. Sealed sources
5. Bioassays

E. Proper handling of radiopharmaceuticals
1. Receipt and monitoring of shipments
2. Storage
3. Dispensing
4. Disposal

F. External radiation protection
1. Instrumentation
a. Radiation field measurements
b. Calibration
2. Reduction of exposure levels
a. Time, distance, shielding
b. Labeling
c. Clinical sources of exposure

G. Internal radiation protection
1. Pathways for internal exposure
a. Ingestion
b. Inhalation
c. Absorption
2. Prevention of internal contamination
a. Handling techniques
b. Laboratory hygiene
c. Surveys, wipe tests
d. Exhaust systems

H. Protection of nonradiation personnel
1. Patients
2. Visitors
3. Other medical personnel
4. The fetus
5. Patient family members

I. Emergency procedures
1. Minor versus major spills or releases
2. Decontamination of personnel

J. Regulations and licensing
1. Sources of information
a. NRC regulatory guides
b. NCRP and ICRP
c. CDRH
d. State agencies
2. Regulations governing local users
a. Code of Federal Regulations
b. State regulations
3. Reports and records
a. Receipts, disposal, inventory
b. Surveys
c. Personnel exposures
d. Instrument calibrations
e. Misadministrations
4. Licensing
a. Physician credentialing
b. Private physician license
c. Hospital nuclear medicine license
d. Broad-scope license

IMAGING PROCEDURES: CARDIOVASCULAR SYSTEM

I. General Considerations for Cardiac Studies

A. Important anatomic relationships
1. Left ventricular myocardial segments
a. Standardized SPECT image orientation and nomenclature
2. Coronary artery anatomy
3. Coronary artery dominance and other major individual differences
4. Collateral vessels
5. Congenital anomalies

B. Physiology
1. Regional myocardial blood flow hemodynamics
a. Measurement of coronary flow reserve
b. Intracoronary Doppler flow measurements
c. Contrast echocardiography
d. Digital subtraction angiography
2. Pressure/volume relationships
3. Myocardial necrosis
4. "Stunned" and "hibernating" myocardium
5. Myocardial viability
6. Exercise physiology

C. Clinical presentation: stable coronary artery disease
1. Typical angina pectoris
2. Atypical angina
3. Nonanginal chest pain
4. Dyspnea as a symptom of myocardial ischemia

D. Clinical presentation: unstable ischemic heart disease
1. Acute myocardial infarction
a. Q-wave

b. NonQ-wave
2. Unstable angina pectoris
3. Postreperfusion

E. Clinical presentation: heart failure
1. Left heart failure
a. Classes I–IV
2. Systolic dysfunction
3. Diastolic dysfunction
a. Restrictive cardiomyopathy
b. Constrictive pericardial disease
4. Right heart failure
5. Pulmonary hypertension
6. Cardiomyopathy
a. Primary
b. Ischemic

F. Forms of stress (advantages, disadvantages and limitations)
1. Bicycle (upright, supine)
2. Treadmill (Bruce, Balke and Naughton protocols)
3. Pharmacologic stress
4. Isometric handgrip
*5. Cold pressor
*6. Pacing (atrial, esophageal, other)

G. Adequacy of exercise
1. Maximum limit by symptoms
2. Aerobic capacity
3. Heart rate response as percentage of predicted maximum
4. Heart rate × systolic blood pressure (double product)
5. Indications for submaximal exercise

H. Principles of exercise electrocardiographic interpretations
1. Serious and not so serious arrhythmias
2. S-T segment depressions and elevations
3. Uninterpretable electrocardiograms (left bundle branch block, permanent pacemaker)
4. Difficult to interpret electrocardiograms (resting ST-segment changes, digoxin therapy, WPW)

I. Effects of various medications on exercise and response to exercise
1. Beta-blocking agents
2. Calcium channel-blocking agents
3. Vasodilators
4. Digitalis
5. Nitrates

II. Myocardial Perfusion Imaging

A. Radiopharmaceuticals
1. Thallium-201
2. Technetium-99m-teboroxime
3. Technetium-99m-sestamibi
*4. Investigational ^{99m}Tc-labeled agents
*5. IPPA

B. Selection of type of study according to clinical problem to be evaluated
1. Immediate poststress and delayed ^{201}Tl imaging
2. Repeat studies late after exercise (18–24 hr) with ^{201}Tl
3. Reinjection of ^{201}Tl
4. Rest imaging alone
5. Rest and delayed imaging
6. Protocols for separate stress and rest studies with ^{99m}Tc agents

C. Clinical applications
1. Coronary artery disease
a. Angina pectoris: location and extent of ischemia
b. Unstable ischemic heart disease
c. Acute and/or chronic myocardial infarction: extent, severity, prognosis, ischemia, viability
d. Chest pain of uncertain etiology
e. Positive ECG treadmill test
f. Uninterpretable exercise ECG
g. Hemodynamic significance of borderline arteriographic findings
h. Restenosis after PTCA
i. Function of coronary bypass grafts
j. Risk stratification/prognosis
2. Congenital heart disease
a. Anomalous coronary artery
b. Newborn myocardial ischemia
c. Shunt detection
1. Left-to-right
2. Right-to-left
3. Pulmonary hypertension
a. Chronic obstructive pulmonary disease
b. Valvular heart disease
4. Idiopathic hypertrophic subaortic stenosis

D. Methods of examination: planar imaging
1. Proper mode and time of tracer injection
2. Time interval from injection to imaging
3. Need for multiple views
4. Time per view
5. Pulse height discrimination (two peaks)
6. Patient positioning (especially left lateral)
7. Differences between postexercise and rest only imaging

E. Methods of examination: SPECT imaging
1. Time interval from injection to imaging
2. Pulse height discrimination (two peaks)
3. Patient positioning
4. Continuous acquisition versus fixed angular (step and shoot) acquisition
5. Time per planar projection
6. Number of projections
7. 180° versus 360° acquisition (trade-offs)
8. Differences between planar and SPECT acquisition protocols

9. SPECT quality control
10. Gated SPECT

F. Computers/imaging processing
1. Image enhancement techniques
2. Background subtraction techniques (i.e., interpolative background subtraction)
3. Stress/delayed image normalization
4. SPECT algorithms
a. Backprojection reconstruction
b. Filtering routines
c. Display techniques
d. Oblique angle reconstruction methods
e. Motion detection correction
5. Thallium-201 quantification
a. Methods for evaluation of ^{201}Tl concentration
b. Evaluation of ^{201}Tl washout and kinetics
c. Thallium-201 reversibility
d. Thallium-201 redistribution (difference from reversibility)
e. Definition of normal limits (patients with normal coronary arteries versus low probability of disease)
f. Need for separate normal files for stress, rest and dipyridamole
g. Sources of error
h. Attenuation correction methods
i. Profile techniques (circumferential versus linear)
j. SPECT quantification (polar coordinate functional maps)

G. Image and data interpretation
1. Normal patterns versus abnormal ones
2. Fixed defect
3. Reversible defect
4. Mixed, fixed and reversible defect
5. "Reverse" redistribution
6. Increased lung activity
7. LV cavity dilatation—fixed or transient
8. Slow ^{201}Tl washout as a marker of ischemia
9. Right ventricular uptake (differences between rest and exercise studies)

H. Clinical accuracy and sources of error in interpretation
1. Bayesian analysis
2. Causes of false-positives
3. Causes of false-negatives
4. Quantitative analysis of washout (effects of submaximal exercise, infiltrated dose, and carbohydrate loading)
5. Differences between planar and SPECT imaging: artifacts
6. Soft-tissue attenuation and patient motion

I. Relationship to other diagnostic tests
1. Stress electrocardiogram
2. Exercise radionuclide ventriculography
3. Exercise two-dimensional echocardiography
4. Conventional indices of myocardial infarction (resting electrocardiogram and enzymes)
5. Exercise digital left ventriculogram
6. Digital coronary flow reserve
7. Fluoroscopy of the coronary arteries
*8. Fast CT
9. Cardiac MRI
10. Signal-averaged ECG
11. Cardiac catheterization
12. PET

III. Myocardial Infarct Avid Imaging

A. Pertinent tissue changes in myocardial necrosis

B. Anatomic locations of infarcts according to distribution of coronary arteries

C. Method of examination
1. Radiopharmaceutical
a. Technetium-99m-pyrophosphate
b. Indium-111-antimyosin
2. Time delay until start of imaging
3. Selection of views and count accumulations
4. Decision about later views
5. SPECT

D. Interpretation and significance in each patient
1. Normal or abnormal
2. If abnormal, assign grade to severity of infarct
3. Location and extent of infarct
4. Importance of length of time from onset of symptoms
5. Extracardiac abnormalities

E. Clinical accuracy for acute myocardial infarction
1. Causes of false-positive results
2. Causes of false-negative results
3. Significance of prolonged abnormal test

IV. Cardiac Blood-Pool Imaging with the Gated Equilibrium Technique

A. Exercise principles
1. Proper patient selection and contraindications
2. Patient instruction
3. Safety principles during monitoring
4. Treatment of acute exercise arrhythmias
5. Indications for stopping exercise
6. Myocardial blood flow demand during exercise and limitations imposed by coronary artery disease
*7. Estimation of cardiac work, oxygen consumption and metabolic equivalents
8. Effects of conditioning
9. Physiologic changes following the cessation of exercise
a. Venous pooling

B. Principles of gated equilibrium imaging
1. Different methods of red blood cell labeling

2. Alternative collimators
3. Supine versus upright exercise
4. Imaging time and framing rate
5. List versus frame mode acquisition
6. Effects of arrhythmias
7. Arrhythmia rejection methods
8. Special problems associated with permanent pacemakers

C. Ejection fraction determinations: left ventricle
1. Fixed versus variable region of interest
2. Edge detection algorithms
3. Multiple frame versus end-diastole/end-systole
4. Background determination
5. Validation studies
6. Reproducibility

D. Ejection fraction determinations: right ventricle
1. Optimal patient positioning
2. Right atrial contribution to end-systolic image
3. Background

E. Regional wall motion assessment
1. Multiple views
2. Terminology
3. Correlation of different segments with coronary artery anatomy
4. Grading systems
5. Validation studies
6. Reproducibility
7. Quantitative methods

F. Ventricular volume determinations
1. Relative changes from rest to maximum exercise
2. Count-based versus geometric methods
3. Attenuation correction
4. Technical limitations
5. Normal limits
6. Physiologic factors affecting ventricular volumes
7. Validation studies
8. Reproducibility

G. Measurement of diastolic function

H. Aortic or mitral regurgitation
1. Chamber sizes
2. Regurgitant fractions
3. Ventriculographic outputs
4. Technical limitations

I. Phase and amplitude imaging
1. Mathematical principles
2. Definition of ventricular boundaries
3. Definition of early ventricular activation
4. Assessment of wall motion
5. Clinical applications

J. Clinical applications for rest only or rest-exercise testing
1. Diagnosis of coronary artery disease
2. Assessment of severity of coronary artery disease
3. Assessment of therapeutic intervention
4. Complications of coronary artery disease
5. Complications of myocardial infarction
6. Prognostic implications
7. Timing of valvular surgery
8. Assessment of congestive cardiomyopathies
9. Evaluation of hypertrophic cardiomyopathy
10. Congenital heart disease
11. Assessment of dyspnea
12. Monitoring doxorubricin toxicity
13. Miscellaneous

V. Cardiac Blood-Pool Imaging with the First-Pass Technique

A. Comparison with gated cardiac blood pool equilibrium

B. Method
1. Mode of injection
2. Synchronization with ECG
3. Evaluation of bolus quality
4. Transit time
5. Normal versus abnormal patterns
6. Ejection fraction
   a. Left ventricle
   b. Right ventricle
7. Regional wall motion
8. Intracardiac shunt measurements
9. Computer data processing

C. Interpretation
1. LVEF normal, elevated or decreased
2. RVEF normal, elevated or decreased
3. Wall motion
4. Shunts

D. Accuracy in clinical use
   a. LV evaluation
   b. RV evaluation
   c. Doxorubricin toxicity
   d. Coronary artery disease

E. Relationship of interpretation to each patient's illness

***VI. Cardiac Flow Imaging (Angiocardiography)**

*A. Anatomy and pathophysiology of cardiac valvular disease and intracardiac and great vessel shunts

*B. Examination procedure
*1. Choice of radiopharmaceutical and dose for single or serial injections
*2. Mode of injection
*3. Timing of rapid sequence images
*4. Computer acquisition format
*5. Patient position
*6. Duration of test or test phase

*C. Interpretation
*1. Description of findings
*2. Conclusions related to clinical problems

*D. Clinical indications and usefulness

*1. SVC obstruction
*2. Congenital anomalies of cardiac chambers
*3. Intracardiac or great vessel shunts
*4. Valvular disease
*5. Dextrocardia
*6. Vessel transposition
*7. RV thrombus or atresia

***VII. Vascular Flow Imaging (Peripheral Angiography)**

*A. Pertinent concepts of anatomy and diseases altering arterial flow dynamics
*1. Intravascular and external compression causes of obstruction of large, medium or small arteries
*2. Neck and cerebral vessels
*3. Thoracic and arm vessels
*4. Pelvic and leg vessels
*5. Hepatic perfusion abnormalities
*6. Renal blood flow disorders

*B. Method of examination
*1. Choice of radiopharmaceutical and dose
*2. Site and mode of injection
*3. Patient positioning
*4. Timing of rapid sequence images
*5. Use of digital computer acquisition and display
*6. Repeat procedure with change in position or other condition
*7. Combination with other procedures such as liver, bone, brain or kidney imaging

*C. Interpretation
*1. Description of normal and/or abnormal findings
*2. Conclusion related to clinical problem

***VIII. Venous Thrombosis Imaging (Venography)**

*A. Pertinent concepts of anatomy and venous flow
*1. Normal venous patterns in the pelvis and legs
*2. Individual variations
*3. Characteristics of deep and superficial venous flows in the legs and pelvis
*4. Patterns and progression of deep venous thrombosis and their clinical significance
*5. Extravascular causes of deep venous occlusion

*B. Method of examination
*1. Flow type (dynamic) or blood pool type venogram
*2. Radiolabeled fibrinogen
*3. Monoclonal antibody imaging
a. Advantages and limitations of each
b. Choice of radiopharmaceutical, dose, site and mode of injection of each type
*4. Selection and timing of views
*5. Patient position and parts of body to be imaged
*6. Lung views?

*C. Indications
*1. Pain and/or swelling of leg or legs
*2. Pelvic pain
*3. Rapid onset of dilated superficial abdominal or leg veins
*4. Source of pulmonary emboli
*5. Repeat test for progression, improvement or recurrence

*D. Interpretation
*1. Normal versus normal variation versus deep venous occlusion
*2. Relationship of imaging findings to clinical problem
*3. Abnormalities on lung views, if available

*E. Competitive/complimentary diagnostic modalities
*1. Impedance plethysmography
*2. Doppler
*3. Vascular MRI
*4. Contrast venography

***IX. Iodine-131 and Iodine-123-MIBG**

*A. Patient dosimetry
*B. Injection/imaging protocols
*C. Clinical indications
*1. Myocardial infarction
*2. Cardiac transplantation
*3. Prognostic value

X. PET Imaging

A. Radiopharmaceuticals
1. Perfusion imaging
a. Nitrogen-13-ammonia
b. Oxygen-15-water
c. Rubidium-82
2. Glucose metabolism
a. Fluorine-18-fluorodeoxyglucose
3. Fatty acid metabolism
a. Carbon-11-palmitate
b. Carbon-11-acetate

B. Comparison to SPECT
C. Quantitation of myocardial blood flow
D. Identification of viable myocardium
E. Cost considerations

XI. Reimbursement Issues

A. CPT codes
B. Safe harbor regulations
C. Self-referral regulations

PART II: LABORATORY EXPERIMENTS AND EXERCISES

A. Experiments (2–4 hr each):

1. Camera set-up experiment
2. Planar QC experiment
3. SPECT QC experiment
4. Measurement of planar performance parameters (LSFs, PSFs, FWHM, FWTM, sensitivity, etc.)
5. Measurement of SPECT performance parameters (same as above + phantoms)

6. Radiation protection lab (ALARA report, survey meter, mock decontamination, etc.)
7. Filtering experiment
8. Dose calibrator
9. SPECT processing QC

B. Exercises:

Five to ten patients each, process the following type of studies:

1. Equilibrium radionuclide ventriculography (LV and RV EF, phase analysis, functional images)
2. First pass radionuclide angiocardiography (same)
3. Reconstruct tomographic perfusion studies + polar quantification and/or
4. Planar perfusion studies with quantification (including washout)

PART III: SPECIFIC TRAINING PROGRAM REQUIREMENTS

A. It is strongly recommended that any institution that sponsors a cardiovascular nuclear medicine training program should satisfy the following:

1. The number of clinical cardiovascular nuclear medicine cases performed should significantly exceed the minimum number of cases required for individual physician participation (see B below). This is necessary so that cases used for training represent the highest quality, most clinically relevant studies. The absolute number of cases performed by the institution per year is not specified in these guidelines.
2. A teaching file of cardiovascular nuclear medicine cases must be readily available to trainees.
3. Correlative imaging modalities, including at least cardiac catheterization and two-dimensional echocardiography, should be performed at the sponsoring institution.
4. The sponsoring institution should be involved in research in cardiovascular nuclear medicine.
5. A quality improvement (TQM) program should be in place which monitors and evaluates technical and clinical aspects of patient care.
6. The faculty roster must include individuals who are responsible for training in basic sciences, including radiation safety, physics and radiopharmacy.
7. An academic affiliation with a medical school is recommended, but not required.

B. The following *minimum* case requirement is recommended for each trainee:

Functional imaging: 150
Perfusion imaging: 500

The trainee should be involved in the performance and interpretation of these cases. Of the perfusion scans, a minimum of 50 should be planar and a minimum of 350 should be SPECT. At least 50 (or 10%) perfusion scans should be performed with pharmacologic stress.

C. For trainees in cardiovascular nuclear medicine who have not already completed a cardiology fellowship (i.e., nuclear medicine and radiology residents) rotations in the cardiac catheterization and exercise physiology (treadmill) laboratories should be mandatory. Trainees should directly observe procedures, but are not required to perform them.

APPENDIX

The following individuals were responsible for the original training guidelines put forth by the Education and Training Committee, October 1, 1989: Ralph J. Gorten, MD, Kelsey-Seybold Clinic, Houston, TX; Manuel Brown, MD, Mayo Clinic, Rochester, MN; C. Craig Harris, MS, Duke University Medical Center, Durham, NC; Dennis P. Swanson, MS, Henry Ford Hospital, Detroit, MI; Richard J. Vetter, PhD, Mayo Clinic, Rochester, MN; Harvey J. Berger, MD, Centocor, Inc., Malvern, PA; Raymond J. Gibbons, MD, Mayo Clinic, Rochester, MN; Gerald M. Pohost, MD, University of Alabama at Birmingham, Birmingham, AL; H. William Strauss, MD, Massachusetts General Hospital, Boston, MA; Robert J. Cowan, MD, Bowman-Gray School of Medicine, Winston Salem, NC; Fred A. Mettler, Jr., MD, University of New Mexico School of Medicine, Albuquerque, NM; Warren H. Moore, MD, Baylor College of Medicine, Houston, TX; Lawrence R. Muroff, MD, University Community Hospital, Tampa, FL; Barry A. Siegel, MD, Washington University School of Medicine, St. Louis, MO; William D. Kaplan, MD, Harvard University School of Medicine, Boston, MA.