Core Curriculum for the Training of Pediatric Invasive/Interventional Cardiologists: Report of the Society for Cardiac Angiography and Interventions Committee on Pediatric Cardiology Training Standards


Within the field of pediatric cardiology, a number of subspecialty fields are generally recognized. Some of these overlap. For example, most electrophysiologists also would consider themselves to be clinical cardiologists. Some fields, however, are relatively mutually exclusive. For example, most clinical pediatric cardiologists would not consider themselves to be electrophysiologists and would admit that there is a different knowledge, skill, and experience base that separates an electrophysiologist from other specialists within the broader field of pediatric cardiology. Likewise, it is our opinion that a separate knowledge, skill, and experience base exists among pediatric invasive/interventional cardiologists. The purpose of this report is to define the unique knowledge and skill base required for the training of an invasive pediatric cardiologist. The scope of this report is limited to the training of invasive/interventional cardiologists dealing with the treatment of pediatric patients and the cardiac diseases most often encountered in these patients.

This report describes in detail the core curriculum suggested for the training of an invasive pediatric cardiologist. For these purposes, invasive pediatric cardiology encompasses all aspects of pediatric diagnostic cardiac catheterization, whether congenital or acquired. Additional curriculum regarding training for therapeutic or interventional procedures is also addressed because of today’s needs: most pediatric cardiac catheterizations are performed to acquire specific data that cannot be obtained otherwise by non-invasive technologies and are required for the best medical or surgical management. However, more and more frequently the need for a cardiac catheterization entertains the possibility of having to proceed with an interventional procedure, and therefore, to conserve the vessels of pediatric patients as well as to consider costs, any invasive pediatric cardiologist should be well trained in most of the accepted interventional pediatric cardiology procedures.

The curriculum is divided here into five major sections followed by a bibliography keyed to those sections. Also included is a suggested format for the objective evaluation and documentation of the progress of invasive pediatric cardiology fellows. It is intended to complement the core curriculum and provide a means for standardizing the evaluation of invasive pediatric cardiology fellows. © 1996 Wiley-Liss, Inc.

SECTION 1. PRINCIPLES OF RADIOGRAPHIC IMAGING AND RADIATION SAFETY

I. Introduction

By completing the clinical cardiology rotation through the Cardiac Catheterization Laboratory, the pediatric cardiology fellow should master a core body of knowledge/skills relative to the principles of radiographic imaging and radiation safety that will ensure complete, safe, and diagnostic studies.

II. Radiographic Imaging

A. Principles of Image Quality
   1. Exposure factors

   a. kV
   b. mA
   c. Pulse width

2. Exposure
   a. Distance
      (1) SID
      (2) SOD
   b. Collimation
   c. Framing rate
      (1) 30 fr/sec
      (2) 60 fr/sec

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d. Optimal position views
   (1) according to congenital malformation,
   cardiac position, and situs
   (2) based upon individual heat (vertical vs.
   horizontal)
   (3) optimal angulated views
e. Optimal protective lead barriers

3. Contrast
   a. X-ray penetration
   b. Scatter radiation
   c. Exposure level
   d. Imaging chain components
      (1) image intensifier
      (2) cine film
      (3) video system
4. Blur (unsharpness)
   a. Motion
   b. Focal spot size
   c. Imaging chain components
      (1) image intensifier
      (2) optical system
      (3) video chain
5. Image noise

B. Cine-Imaging Chain

1. X-ray generator
2. X-ray tube
   a. Focal Spot (cine vs. fluoro)
   b. Anode
   c. Collimation-use of wedge filters
   d. Grid
3. Image intensifier
   a. Input phosphor
   b. Output phosphor
   c. Magnification modes
   d. Dose relationship
4. Optical system (camera)
   a. Beam splitter
5. Video system
   a. Raster lines
   b. Line pair resolution
6. Image storage
   a. Cineangiographic film
      (1) characteristic curve
      (2) film processing
      (3) film projection
   b. Digital principles

C. Image Acquisition

1. Injector parameters
   a. Amount to inject according to anatomic
      (physiologic) lesion and total amount
      permitted
   b. Time of injection
   c. Pressure limits
   d. Rate of rise
   e. Familiarity with types of contrast materials
      and absorption characteristics

2. Recording equipment
   a. Cine
   b. Digital technology
   c. Archival technology

D. Angiography/Ventricularography/Aortography

1. General
   a. SID/SOD/collimation
   b. Framing rate
   c. Injector settings
      (1) flow rate
      (2) pressure cutoff
      (3) rate of rise
   d. Patient breathing techniques
2. Arteriography (pulmonary, coronaries, etc.)
   a. Selection of diagnostic views for anatomy
      (positioned angles)
   b. Exclusion of vessel overlap
   c. Elucidation of tortuous vessels
   d. Minimizing foreshortening
   e. Panning techniques
   f. Hand-injection techniques
   g. Patient breathing techniques

E. Interpretation of the Exam

1. Projector and digital systems operation
2. Awareness of artifacts (e.g., mock effect, foreshortening)
3. Importance of orthogonal views
4. Report generation of results
5. Familiarity with research techniques
6. Familiarity with angiometric and volumetric techniques
7. Correction for X-ray magnification (determination
   of vessel and valve diameters and ventricular volumes)
8. Knowledge of possible measurement errors and
   underlying model assumptions
9. Knowledge of X-ray density measurement for densitometry
   (determination of regurgitant fraction
   and ejection fraction in valvular insufficiency)

III. RADIATION SAFETY

A. Measurement

1. Exposure (roentgen, R)—air kerma
2. Absorbed dose (rad, r; 100 rad = 1 gray (Gy))
3. Dose equivalent: rem (100 rem = 1 sievert, Sv)
4. Effective dose equivalent (EDE) weighted average
   of physical distribution of dose in the body
   and radiosensitive organs
B. Types of Radiation Injury
   1. Nonstochastic injury (direct threshold doses) deterministic effect
      a. Acute/subacute damage to irradiated tissues
      b. Cataract, skin burn, depilation, e.g.
      c. Known threshold doses
   2. Stochastic injury (future—no threshold)
      a. Assumed to have no threshold
      b. Probability of injury is proportional to dose at any level
      c. Genetic damage, future malignancy, e.g.

C. Radiation Safety Guidelines/Dose Limits
   1. Maximum permissible doses (MPD)
      a. General exposure guidelines for radiation workers
      b. Radiosensitive organs—tissue weighting factors
      c. Physician responsibility to obtain information at minimum patient radiation dose
   2. Fluoroscopy vs. cine-radiation exposure
      a. Fluoro 10 R/min/max allowable (24 R>J.min ave)
      b. HLC fluoro (fluoro boost, high contrast, image enhancement)
      (1) no limit on exposure radiation but:
         (a) basic fluoro must be 5 R/min
         (b) continuous audible signal required
         (c) requires continuous manual/ pedal activation
      c. Cine run—40 R/min = 10 x fluoro (1 min cine = 10 min fluoro)

D. Methods of Measurement (dosimetry)
   1. Film badge
   2. TLD

E. Risks of Radiation
   1. Genetic risk
   2. Somatic risk—postnatal
      a. Cataracts
      b. Carcinogenesis
         (1) bone marrow
         (2) breast
         (3) thyroid
   3. Somatic risk—prenatal (1st trimester vs. 2nd, 3rd trimester)
      a. Pregnant patient
         (1) pelvic lead
      b. Pregnant personnel
         (1) fetal total body dose 0.5 rem for entire pregnancy
         (2) less than 50 mrem/mo on badge under apron

F. Radiation Doses
   1. Patient exposure

   a. Minimize by collimation
   b. Minimize fluoro time
   c. Minimize cine time
   d. Film at lowest clinically acceptable frame rate
   e. Cine and fluoro at lowest clinically acceptable magnification
   f. MD responsibility to obtain necessary diagnostic information at minimal patient radiation dose

2. Personnel exposure
   a. Primary beam exposure
   b. Secondary—scatter/leakage
   c. Angulation
   d. Brachial, axillary, or umbilical—much higher dose
   e. Distance—inverse square law
   f. ALARA—as low as reasonably achievable
   g. Monitor fluoro time
   h. Limit cine to diagnostic necessity

3. Shielding
   a. Aprons
   b. Thyroid collars
   c. Glasses
   d. Movable barriers

SECTION 2. DIAGNOSTIC CARDIAC CATHETERIZATION

I. Indications
   It is impossible to formulate absolute indications or contraindications for cardiac catheterizations. However, it should be stressed that pediatric cardiac catheterization clearly should be goal-oriented to elucidate further the nature of the patient’s problem, since catheterization techniques today are usually aimed at clarification of diagnostic details that 2D Echo/Doppler, MRI, electron-beam CT, or spiral CT could not provide, as well as to set the background for future therapeutic interventions. The invasive pediatric cardiologist should learn to formulate an individual protocol and design the procedure that will obtain the most useful information in the least traumatic manner. The trained invasive pediatric cardiologist should demonstrate capabilities of acquiring the needed physiologic data and optimal angiographic views in all vicombinations of situs, dextro, and levocardia, all varieties of concordant as well as discordant AV and VA connections. The trainee should be able to conduct a diagnostic cardiac catheterization and interpret the findings noted below.

A. Define Cardiovascular Anatomy
   1. Morphology
2. Position
3. Connections
   a. Systemic and pulmonary veins
   b. Coronary anatomy
   c. Atria
   d. AV valves
   e. Ventriles and outflow tracts
   f. Proximal systemic and pulmonary arteries
   g. Peripheral systemic and pulmonary arteries

B. Measure and Calculate Central and Peripheral Hemodynamics
1. Blood pressure in the systemic and pulmonary arteries and veins
2. Blood flow in systemic and pulmonary circulation (by conventional methods as well as by Doppler flow wires)
3. Calculate shunts
4. Calculate vascular resistance in pulmonary and systemic beds
5. Calculate valve areas

C. Other
1. Evaluate cardiac systolic and diastolic function
2. Monitor changes in hemodynamics and cardiac function in response to drug challenges, respirations, or interventions (percutaneous or surgical)
3. Electrophysiologic studies and intervention (only for those being trained in pediatric cardiac electrophysiology)
4. Endomyocardial biopsy

II. Contraindications
A. The Only Absolute Contraindications
1. Refusal of a mentally competent adult (>16 years of age) patient, or of the parent(s) (guardians) in children, infants, or neonates to consent to the procedure
2. Absence of an experienced pediatric cardiac angiographer and/or suitable laboratory facilities

B. Relative Contraindications to be Cautiously Applied to Individual Patient
1. Significant electrolyte abnormalities or digitalis toxicity
2. Uncontrolled hypertension
3. Febrile illness (not related to endocarditis)
4. Decompensated congestive heart failure
5. Bleeding diathesis: includes patients receiving anticoagulation therapy whose prothrombin time is >18 seconds (INR>2)
6. Presence of a noncardiac disease that precludes long-term survival
7. Refusal to undergo surgical or interventional curative or palliative procedures regardless of the outcome of the catheterization (angiogram)
8. Previous history of severe contrast reaction
9. Active gastrointestinal bleeding
10. Pregnancy, especially during 1st trimester

III. Preprocedural Preparation
A. Trainee Familiarity with Preprocedural Preparations
1. Education and informed consent: The physician should meet with the patient (parents, guardians) and the patient’s family in a relaxed atmosphere. During this meeting, the patient should be informed about the indications and potential risks of cardiac catheterization. The patient (parents, guardians) also should be told what to expect during the procedure. It is important not to understate the discomfort or duration of the procedure (it is not uncommon for older patients to complain of lower back pain due to the nature of the fluoroscopic table). If cardiac catheterization is being performed as a preprocedural evaluation, an explanation of the contemplated cardiac surgery or transcatheter interventions should be provided.

B. History and Physical Examination
1. A thorough cardiac history should be taken. The presence of cardiovascular symptoms should be documented when appropriate. The past medical history should be obtained with particular attention to conditions that increase the risk of cardiac catheterization (renal insufficiency, allergies, insulin-requiring diabetes, pulmonary insufficiency, reactive airway disease immunosuppression, malignant supraventricular or ventricular arrhythmias, etc.). Any history of allergic reactions to contrast agents, iodine, or shellfish should be documented. A complete physical examination should be performed with special attention to the cardiac, pulmonary, and vascular systems. Peripheral pulses should be palpated and vascular bruises should be auscultated so that the appropriate vascular access site can be chosen. Physicians should make an effort to document occluded access sites, so in the future if further procedures are needed, that specific site can be spared from a frugal (and costly in time and money) attempt.

C. Laboratory Examination
1. The physician should review a current chest X-ray if available, electrocardiogram, and pertinent laboratory data. Echocardiograms and past catheterization and surgical records must be reviewed when applicable, and a CBC is indicated in all pediatric patients prior to or during the procedure. It is generally accepted that an electrocardiogram and chest X-ray should be performed within 1 week of the cardiac catheterization. A CBC is indicated in all pediatric patients prior to the pro-
D. Premedications and Preparation of Patients

1. Patients should be NPO 2–6 hours (depending on age, weight, etc.) prior to the procedure, avoiding, however, a dehydrated state.

2. Most neonates do not require precatheterization sedatives; however if discomfort is anticipated, the patient should be sedated according to individual cardiologist preference (Fentanyl Citrate 1–3 mcg/Kg/h. iv drip) and paralyzed (Pancuronium Bromide 0.04–1 mg/Kg iv. q. 30–60 min. PRN). Infants are particularly susceptible to CNS depressant effects of narcotics. Many precatheterization sedative protocols are available, and they should be chosen according to information that is expected to be obtained; some sedatives are potent vasodilators and should be avoided in patients with ventricular outflow-tract obstructions, TOF, and patients with pulmonary vascular disease. Ketamine 0.5–2.0 mg/Kg iv. is a rapidly acting dissociative anesthetic that does not lower systemic resistance (excellent in patients prone to cyanotic spells) and does not depress pharyngeal or laryngeal reflexes and promotes salivation.

3. Oral anticoagulation should be held until the INR is < 2. In patients who are chronically anticoagulated with an oral agent, hospitalization and heparin administration may be necessary for 48 hours prior to the procedure. When necessary, anticoagulation may be reversed with fresh frozen plasma. The administration of parenteral vitamin K should be avoided because of the possible induction of a hypercoagulable state.

4. Intravenous access should be obtained prior to the procedure in small infants and in unstable or deeply cyanotic patients. To avoid dehydration and to decrease the incidence of renal toxicity, IV fluids are necessary. Liberal hydration should be avoided, however, in patients with a history of congestive heart failure.

5. Insulin and oral hypoglycemic agents should be adjusted in diabetic patients to avoid hypoglycemia.

6. An antihistamine is frequently prescribed to provide additional sedation and as prophylaxis against allergic reactions. The preferred agent is promethazine hydrochloride 0.5–1.0 mg/Kg (Penergan) P.O. to be administered along with the meperidine 1.5–2.0 mg/Kg (Demerol) P.O. and chlorpromazine 1.0 mg/Kg (Thorazine) P.O.—“lytic cocktail”—~30–45 min prior to the procedure. Contraindications include hypersensitivity to structurally related antihistamines.

7. Prophylactic antibiotics are not routinely required.

8. Special precautions are warranted in patients with known contrast allergies. In addition to antihistamines, steroids should be administered the night prior to the procedure. Either oral (i.e., prednisone 0.5 mg/Kg P.O.) or parenteral (i.e., hydrocortisone succinate 1–2 mg/Kg iv bolus) administration is acceptable. H2 blockers (i.e., cimetidine 5–40 mg/Kg/day) also may help reduce the risk and severity of severe contrast reactions.

E. Transport to Catheterization Laboratory

1. In neonatal transport, the same guidelines used for extramural transport should be applied for transport from the NICU to the catheterization laboratory.

2. The patient’s hemodynamics should be as stable as possible, and blood volume replacement should be completed before transport.

3. All intravenous and arterial lines should be properly secured.

4. Maintain a constant body temperature control and make certain that the catheterization laboratory has the adequate temperature for control of patient temperature and comfort.

5. For patients on ventilator support, the respirator should be set up in the catheterization laboratory ahead of time, and during the transport the patient should be hand-bagged by one dedicated operator.

6. Monitoring during transport should include but not limited to ECG and pulse oximeter.

IV. Procedural

A. Patient Evaluation and Monitoring

1. Patients should be positioned on the imaging table to allow proper angiographic views (securely strapped when appropriate) to be obtained.

2. The chosen access site must be exposed. For the brachial and axillary sites, proper positioning of the arm board and surgical lamp should be noted. For the femoral approach, the site must be shaved ahead of time, and during the transport the patient should be hand-bagged by one dedicated operator.

3. In severely obese patients, the pannus should be taped in a way to provide clear access to the groin.

4. A functional separate IV (preferable 18G, when feasible, depending on the size of the child) must be present in unstable patients prior to the proce-
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...dure. IV access must be available throughout the entire procedure.
5. Comfort measures such as pillows, arm boards, and table pads should be employed as appropriate.
6. Continuous electrocardiographic monitoring of several leads must be instituted.
7. In patients at high risk of ventricular arrhythmias (due to prior history, or acute instability) defibrillation pads should be employed recognizing that they may affect image quality.
8. Emergency resuscitation equipment including intubation, defibrillation, and suction equipment must be available and accessible to the patient.
9. Blood pressure should be monitored continuously using either an automated cuff, finger probe, or indwelling arterial line.
10. Pulse oximetry must be used for all patients.
11. Temperature monitoring for patients < 10 Kg. Measures for control of temperature should be initiated before starting the procedure (thermal wraps, K-pads, heaters, room temperature, etc).
12. Consideration of increased urinary output should be made. In some patients, Foley catheters or condom catheters should be employed. This decision should take into account the anticipated length of procedure, or known difficulties.
13. Patient orientation to the equipment and procedures should be done in a nonthreatening and considerate fashion.

B. Procedure Planning
1. The order of events should be established prior to starting the procedure. This will be individualized for each patient but should include consideration of:
   a. Patient condition/stability
   b. Minimizing arterial access and time
   c. Minimizing need for repeated measurements
   d. Minimizing need for multiple catheter exchanges
   e. Need for grouping certain measures, i.e., obtaining cardiac output at the same time as valve gradients, oxymetries prior to angiographic studies, etc.
2. In order to accomplish this planning, a clear formulation of the questions to be answered must be established. In general, these include specific questions that have not been answered by other noninvasive studies (2D-Doppler) or confirmation of a doubtful noninvasive data that is essential for the management of the patient.
3. Planning (knowledge of approach) must also establish the likely equipment to be needed, including:
   a. Types of access needle
   b. Types, Fr. and length of sheaths
   c. Types, shapes, length, and G. of guidewires
   d. Routine catheters and styles
   e. Micromanometer catheters
   f. Number of transducers and lines
   g. Oximeter
   h. Blood gases
   i. Thermodilution cardiac output
   j. Polarograph (hood) or in its absence a Douglas bag with a Tissot spirometer and an oxygen analyzer for VO2
   k. Transseptal needle/sheath
   l. Transvenous temporary pacemaker
   m. Pharmacologic interventions
   n. Biopomte

V. Vascular Access
Appropriate indications and uses for percutaneous jugular, subclavian, radial, brachial, axillary, and femoral access must be demonstrated. Lately the transhepatic technique has been described for patients with no venous access. Knowledge of anatomy and appropriate draping, anesthesia, palpation, and proficiency of arterial and venous access using both percutaneous and open approaches is important where appropriate. Development of manual dexterity necessary for wire/sheath placement with minimal trauma to the vessels and recognition of proper wire movement. Knowledge of access site care to avoid line displacement, air emboli or thrombus. Awareness of techniques useful for difficult access, i.e., use of valsalva for venous entry; use of hydrophilic or steerable wires; use of Doppler guided needles; use of long sheaths; use of fluoroscopy with dye injections or bony landmarks; over the wire sheathless technique, etc.

VI. Catheter Manipulation and Hemodynamic Recording
A. Trainee Responsibilities
1. Demonstrates knowledge of basic transducer and recorder function; understands need and rationale for balance, zero, and calibration functions.
2. Is able to troubleshoot and recognize over- or underdampening, lack of waveform, etc.
3. Recognizes normal and abnormal waveforms in each cardiac chamber.
4. Understands appropriate use of the recorder for various pressure sites (i.e., LVEDP on low scale, fast paper speed).
5. Understands potential problems with catheter whip, underdamping, respiratory motion, overwedging, which may lead to false recordings.
6. Demonstrates use of nonballoon catheters as well as balloon flotation to obtain right heart pressures.
Also when to use an end-hole vs. angiographic catheters. "Information should be obtained while you are there; you may never be back."

7. Transseptal: adequate expertise in transseptal left heart catheterization (including usage of the Brockenbrough needle).

8. Demonstrates knowledge of crossing stenotic valve.

9. Able to perform long wire catheter exchanges.

VII. Angiography

A. Trainee Responsibilities

1. Chooses appropriate size and style of catheter.

2. Recognizes improper seating of catheter and/or damping of pressures rapidly and understands implications for injection.

3. Use of hand injection—when appropriate—by only small volumes:
   a. Forceful for "test" injections or cavity injections
   b. Slow and controlled for capillary and vein wedge angiograms.

4. Recognizes and responds to postinjection arrhythmias and/or hypotension.

5. Specifies angiographic views to allow maximal information with minimal contrast and radiation exposure.

6. Can specify proper power injector settings for angiography, ventriculography, and aortography.

7. Is aware of hemodynamic implications of right heart injections.

8. Demonstrates knowledge of the appropriate field to use as well as the focal spot (0.6 mm or less for sharp definition, high kilovoltage, and low milliamperage for maximal penetration, wide grade scale for cardiac angiography; lower kilovoltage and higher milliamperage to obtain higher contrast and edge definition for viewing blood vessels). The best cine film exposure (30 to 90 frames/sec.) according to the structures being filmed.

9. Demonstrates proficient knowledge of the different angiographic contrast agents available and their toxic effects.

10. Demonstrates dexterity at panning and an understanding of proper panning sequence.

11. Communicates with patient what to expect and what their expectations are when appropriated.

VIII. Care

A. General

1. Understands role of laboratory staff nurses and technicians.

2. Effectively communicates confidence and direction to laboratory staff.

3. Effectively communicates assurance to patient. Is appropriate in bedside comments and reacts to unexpected or unusual events professionally so as not to alarm patient.

4. Is attentive to heart rhythm blood pressure and mental/respiratory status at all times; anticipates changes and has a plan for correcting these.

5. Understands when to ask for help or when to discontinue attempts to proceed with study.

6. Is attentive to patient discomfort and appropriate in the use of medication and other comfort measures.

7. Has knowledge of pediatric resuscitation techniques and preferably certified in PALS.

8. Understands importance of a standarized lab protocol known to all personnel.

9. Has knowledge of emergency lab protocol and procedure.

B. Postprocedural

1. Technical considerations
   a. Vascular integrity
   b. Monitoring—holding room
   c. Immediate postprocedure care—where to go
   d. Duration of extremity immobilization—expand
   e. Evaluation of distal vascular integrity

2. Evaluation of complications
   a. Adverse medication reaction
   b. Electrical abnormalities
   c. Mechanical abnormalities
      (1) perforation
      (2) dissections
   d. Left ventricular systolic and diastolic dysfunction
   e. Ischemia
   f. Vascular complications

3. Interpretation
   a. Hemodynamics
      (1) understanding of principles and methods to determine cardiac output
      (2) understanding of principles associated with and calculate stenotic valvular areas
      (3) understanding of intracardiac shunt detection and measurement
      (4) ability to explain pressure measurement and wave form analysis
      (5) calculate resistance
      (6) interpret hemodynamics under different drug challenges
   b. Angiographic
      (1) film review
      (2) understanding of angiographic false positive and negatives
      (3) categorization into classic angiographic subsets
c. Evaluation of cardiac function
4. Reporting
   a. Narrative
   b. Diagramatic
5. Patient communication
   a. Discuss findings with patient and family
   b. Discuss prognosis and alternative treatment strategies

SECTION 3. HEMODYNAMICS

I. Mechanics of the System
   A. Fluid-Filled Systems
      1. Physics
      2. Zero/calibrate/level
      3. Troubleshooting the system
   B. Micromanometer Tip Systems
      1. Physics
      2. Zero/calibrate/level/gating
      3. Troubleshooting the system
   C. Cardiac Output Determinations
      1. Fick
      2. Thermodilution
      3. Indicator dilution curves
   D. Oximetry

II. Normal Physiology
   A. Right Heart Pressures
   B. Left Heart Pressures
   C. Oximetry
   D. Cardiac Output
   E. Exercise
   F. Drug Interventions

III. Abnormal Physiology
   A. Hypotension
      1. Vaso-vagal reactions
      2. Cardiogenic
         (a) ischemic
         (b) nonischemic
      3. Noncardiac causes
         (a) allergic
         (b) volume dependent
   B. Aortic Valve Disease
      1. Mixed aortic valve disease
      2. Low output/low gradient AS
      3. Exercise physiology
      4. Acute vs chronic
   C. Mitral Stenosis
      1. Mixed mitral valve disease
   D. Pulmonic Stenosis
   E. Tricuspid Stenosis
   F. Hypertrophic Cardiomyopathy

   1. Obstructive
      (a) pacing effects
      (b) role of mitral valve replacement
   2. Nonobstructive
   G. Nonhypertrophic Cardiomyopathy
      1. Dilated cardiomyopathy
      2. Restrictive cardiomyopathy
   H. Pulmonary Hypertension
      1. Flow hypertension or reactive
      2. True pulmonary hypertension (pulmonary vascular disease).
         (a) fixed
         (b) vasoactive
      3. Methods of differentiation
         (a) pharmacologic
         (b) mechanical (i.e., unilateral pulmonary artery occlusion)
   3. Primary
   4. Secondary
      (a) intracardiac shunts
      (b) pulmonary venous obstruction
      (c) left heart failure
      (d) congenital or acquired valvular disease
      (e) recurrent emboli
      (f) obstructive lung disease
      (g) other

   I. Pericardial Disease
      1. Tamponade
      2. Constriction
      3. Effusive constrictive disease

IV. Congenital Heart Disease
   A. Intracardiac shunts
      1. Left to right shunt
      2. Right to left shunt
      3. Bidirectional shunt
      4. Balanced shunt
      5. Multiple shunts
   B. PA/IVS-RV Dependent Coronary Circulation
   C. Transposition Physiology
   D. Abnormal Systemic or Venous Drainage
   E. Single Ventricular Anatomy
   F. Malalignment of Inflows and Outflows
   G. Left- and Right-sided Atresia
   H. Aortic Arch Obstruction
   I. Other Complex Heart Disease Combinations

SECTION 4. CARDIAC CATHETERIZATION LABORATORY PHARMACOLOGY

I. Precardiac Cath/Intervention
   A. Previously Prescribed Medications and Preparation of Patient
1. Patient should be NPO 2–8 hours prior to procedure.
2. Heparin should be continued (if clinically indicated) unless a transseptal puncture is anticipated, in which case the ACT should be $\leq 150$ sec.
3. Oral anticoagulants should be held until the INR $< 2$. In patients with chronic oral anticoagulants, hospitalization and heparin administration may be necessary for 48–72 hours prior to procedure. When necessary, oral anticoagulation may be reversed with FFP. The administration of vitamin K should be avoided because of the possible induction of a hypercoagulable state.
4. Insulin administration should be given one-half the usual morning dose the day of the procedure (higher dose may be indicated for an afternoon procedure).
5. Diuretics—often omitted precath.
6. Steroids dependent patients should have their dose adjusted accordingly to the underlying pathology.
7. Antiarrhythmics, digitalis, vasodilators, and antihypertensive preparations are not usually omitted the day of the procedure (except for patients undergoing electrophysiologic examination).

**B. Premedication for Cardiac Catheterization**

1. See section 2 under Premedications and Preparation of Patients

**II. During and Postcardiac Catheterization**

**A. Proficient Knowledge of the Following Drugs:**

1. Different contrast agents: ionics vs. nonionics
2. Additional sedatives and analgesics
3. Medications to reverse the effects of sedatives and analgesics (Narcan, Romazicon)
4. Therapy for bradycardia: Atropine, Isoproterenol (caution in ischemic heart disease such in Kawasaki’s disease etc.)
6. Medications for ventricular ectopy: Lidocaine, Procaainamide, Brefylium, Amiodarone
7. Medications for hypertension: Nitroglycerine, Nitroprusside, Nifedipine, beta blockers
8. Medications for hypotension: crystalloid fluids, colloids (volume expanders) such as Dextran, Plasmanate, Hespan. Catecholamines such as Phenylephrine (Neosynephrine, the only pressor to use in patients with IHSS) Dopamine, Dobutamine, Epinephrine, Norepinephrine, Aamine
9. Medication for congestive heart failure:
   a. Diuretics: Lasix, Bumex, Edecrin
   b. Vasodilators: Nitroglycerin, Nitroprusside
   c. Inotropic agents: Dobutamine, Dopamine, Amriron, Milrinone, Eipenehrine, Norepinephrin, Glucagon (in case of beta blocker excess)
10. Medications for nausea: Phenergan, Dramamine, other phenothiazines
11. Medications for seizures: Valium, Phenytoin
12. Medications for anticoagulation: Heparin
13. Agent used in renal insufficiency: Mannitol, Fursemide
14. Medications for hypocoagulability: Protamien, fresh frozen plasma phytonadione
15. For anaphylaxis: steroids, pressors, antihistamines (including H1 blockers and H2 blockers)
16. For pain: Meperidine, Morphine, Toradol, Demerol, Dilaudid
17. For fever: judicious use of Vancomycin
18. Agents used to evaluate response of abnormal hemodynamics to pharmacologic intervention and to provoke abnormal responses
   a. Acetylcholine, oxygen, hydralazine
   b. Amyl-nitrate, isoproterenol (dynamic outflow tract obstruction)
   c. Dobutamine, PGE1, Prostacyclin, N.O. (pulmonary hypertension)

**SECTION 5. ADDITIONAL CORE CURRICULUM FOR INTERVENTIONAL PEDIATRIC CARDIOLOGY**

**I. Radiographic Imaging and Safety**

**A. Increased Doses**
1. To operator due to prolonged fluoro: chronic radiation injury (e.g., hands)
2. To patients due to multiple repeat and prolonged procedures
   a. Skin burns
   b. Acute hair loss
   c. Most radiation effects will not be seen during hospitalization

**II. Laboratory Techniques**

Proficient knowledge of the clinical indications, contraindications, and anatomic possibilities of offering a successful procedure at equal or less risk than the equivalent surgical alternative. In addition, the interventional pediatric cardiologist must be extensively familiar with all the available equipment in the market of interventional cardiology (including but not limited to the equipment used in adult coronary interventional techniques and interventional radiology) since many technique modalities can be adopted in pediatric interventional cardiology. They must be very familiar with all possible com-
plications as well as the best ways to deal with them. It is imperative for the interventional pediatric cardiologist to put in the appropriate perspective not only his/her qualifications to perform a specific interventional procedure but more importantly his/her true capabilities of performing the procedure in a safe manner for that specific patient given all the circumstances surrounding the case. Also, it is very important to assess the cardiac catheterization laboratory equipment and personnel, as well as the surgical backup, to ensure the safety of the patient undergoing the interventional procedure.

A. Percutaneous Balloon Valvuloplasties

1. Pulmonic
   a. In infants, children, and young adults
   b. Neonates
   c. TOF
   d. Pulmonary atresia

2. Aortic
   a. In infants, children, and young adults
   b. Neonates
   c. Shone’s complex

3. Mitral
   a. Congenital
   b. Parachute
   c. Shone’s complex
   d. Rheumatic

4. Tricuspid
   a. Congenital
   b. Ebstein’s
   c. Tricuspid atresia

B. Percutaneous Balloon Angioplasties

1. Coarctation of the aorta
   a. Natives
      (1) infants, children, and young adult
      (2) neonates (nonductal and ductal dependent)
      (3) Shone’s complex
   b. Recoarctation

2. Pulmonary artery branch stenosis

3. Pulmonary vein stenosis (Scimitar’s syndrome, etc.)

4. Other systemic veins

5. Postop shunt stenosis (B-T, Cavo-pulmonary, Fontan, etc.), conduits and other postops (Mustard, Senning, etc.)

C. Atrial Septostomy

1. Balloon
   a. Rashkind’s technique
   b. Balloon dilatation

2. Park blade

D. Closure Techniques

1. Coil embolization
   a. Collaterals
   b. Shunts

c. PDA

d. Fistulas

2. Occlusion devices (Rashkind’s umbrella, clamshell, buttoned, microvena device, etc.)

E. Stent Placement

1. Systemic veins and venous conduits
2. Pulmonary artery branches
3. Systemic arteries and conduits
4. Pulmonary veins
5. PDA

F. Foreign Body Retrieval

1. Snares
2. Baskets
3. Forceps

III. Intravascular Ultrasound

A. Knowledge of Technology

B. Normal Anatomy and Pathology

C. Assessment of Intervention

D. Ultrasound Angiographic

E. Physiologic Correlations

IV. Management of Complications in Diagnostic and Interventional Catheterization

A. Proficiency in Anticipation, Prevention, Early Detection, and Treatment (including complete cardiorespiratory resuscitation) of Possible Complications or Adverse Side Effects of Interventional Procedures

1. Adverse effects from deep sedation, e.g., hyperventilation, unstable upper airway, respiratory arrest, hypotension.

2. Vascular access complications, e.g., vasospasm, inability to introduce or remove interventional catheters, inability to remove retrieved closure devices from access vessel, post procedural vascular occlusion (heparin and thrombolysis), monitoring of thrombolysis.

3. Handling of large and stiff interventional systems to avoid perforation or dissection, emergency treatment of perforations or dissections on the site (vascular, atrial, or ventricular), including bailout stenting, occlusion of bleeding vessel, pericardio, and pleurocentesis.

4. Electrical abnormalities, e.g., catheter induced atrial flutter or fibrillation, ventricular tachycardia or fibrillation, A-V block or bundle branch block, especially in bifascicular block- “mechanical” conversion, overdrive pacing, cardioversion and defibrillation, emergency pacing.

5. Thrombus or air embolism, e.g., from large delivery systems—prevention and supportive therapy.
6. Reflex bradycardia and hypotension—pharmacological and volume management.
7. Balloon rupture (possible circumferential) and other equipment malfunctions.
8. Hypercyanotic spells—volume overloading, transfusion, sedation, neosynephrine, etc.
9. Myocardial ischemia, severe myocardial dysfunction—pharmacological therapy, intra-aortic balloon pump, or emergency ECMO.
10. Acute major vessel occlusion from embolized large occluder devices.
11. Retrieval of embolized occluder devices or device fragments from various locations.
12. Balloon rupture during stent delivery, stent dislodgement, snaring or entanglement of delivery catheter and stent or occluded device.
13. Acute and severe procedure-induced valve insufficiency.

SECTION 6. BIBLIOGRAPHY

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B. DIAGNOSTIC CARDIAC CATHETERIZATION
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C. HEMODYNAMICS
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