Chapter 4
Angiography: Basics and Contrast Media

Jose Luis Zunzunegui

The cardiac catheterization laboratory plays an important role in the management of children with congenital heart disease by not only enabling diagnosis but, in many cases, providing definitive therapy. This chapter focuses on the importance of adequate planning of the study, optimizing image formation, management of fluoroscopy and cine parameters, and basic knowledge regarding the use of contrast media that allow the cardiologist to lower radiation dose without sacrificing image quality.

4.1 Cardiac Catheterization Laboratory Equipment Overview and Basic Roentgenology

The X-ray tube is a glass tube containing a vacuum with a cathode (negative terminal) and anode (positive terminal). An electric current passes through a tungsten filament coil

J.L. Zunzunegui
Pediatric Cardiology Unit, Gregorio Marañon Hospital,
O'Donell 48-50, Madrid 28009, Spain
e-mail: zunzu69@hotmail.com

G. Butera et al. (eds.), *Cardiac Catheterization for Congenital Heart Disease: From Fetal Life to Adulthood*,
DOI 10.1007/978-88-470-5681-7_4, © Springer-Verlag Italia 2015

(cathode) and heats it, such electrons are “boiled off” the filament (thermionic emission). These electrons are accelerated toward the anode within the tube by application of a large electrical voltage, measured in kilovolts peak (kVp), across the cathode and the anode. This stream of electrons is the tube current, measured in milliamperes (mA). The kinetic energy of these high-velocity electrons, after striking the spinning tungsten disc (anode), is transformed mostly to heat energy and a few X-ray photons. The point at which the electrons impact on the tungsten target is called the focal spot of the X-ray tube. The energy carried by each X-ray photon depends on the applied voltage (kVp), while the rate of X-ray production depends on the tube current (mA). As the X-ray passes through the patient, it undergoes a change. Some of the X-rays are scattered in different directions from the original beam, while the others are absorbed by the tissues; this latter process is known as attenuation. The quantity of X-rays removed varies according to the mass of the patient with the remaining emerging as a beam on the other side. Scattered rays confer no imaging benefit and are a radiation to both the patient and catheterization laboratory personnel.

X-rays that reach the target are converted into electrons once again by interacting with the input phosphor and photocathode; the electrons are then focused and accelerated onto the anode where they strike and emit visible light. The emitted light is then focused and transmitted to a television monitor for viewing and/or storage. An important feature of imaging chain is the *automatic exposure control* (AEC) that exists to ensure relatively constant image brightness. AEC is accomplished by a feedback mechanism from the digital video processor to the X-ray generator; if conditions change such that fewer X-rays exit the patient (e.g., table has been

moved such that a more radiopaque part of the body is now being imaged), then feedback to the X-ray generator will increase the quantity or intensity of the X-ray in order to maintain equal image brightness.

The catheterization laboratory is capable of several imaging modalities. Fluoroscopy is used for real-time viewing and should provide sufficient image quality to view small guidewires. Fluoroscopy imaging should be set to the lowest possible radiation with usable image quality. Nowadays, variable-rate pulsed fluoroscopy is the standard; the X-ray beam is pulsed at 30 or 15 pulses per second or fewer (the lower the pulse frequency, the less the radiation dose, at the expense of a "jerkier motion"). The duration of each pulse is also known as the exposure time and is expressed in millisecond (ms), with typical setting for pediatric cardiac fluoroscopy ranging from 1 to 4 ms per pulse.

Images designed for permanent storage and review are usually obtained in acquisition (cine) mode, although higher quality modern fluoroscopic runs can usually be stored as a lower quality but acceptable alternative in many circumstances. Cine requires approximately 15 times more radiation per frame and should be used sparingly. Cine is always pulsed, and rates of 15, 30, and 60 frames per second are typically available in pediatric catheterization laboratories (whereas most adult studies are performed at 15 frames per second). Faster frame rates are necessary to view rapidly moving structures throughout the cardiac cycle (e.g., prosthetic valve leaflets), or in the setting of extremely high flow rates through a vascular bed (e.g., arteriovenous fistula), and particularly if the patients is tachycardic. Any modification to the standard parameters of the X-ray beam (mA, kV, ms) usually does not produce any significant benefit in image quality and tends to increase the dose of radiation [1, 2].

4.2 Tactics for Radiation Dose Reduction and Image Quality Improvement

4.2.1 Diagnostic Information Should Be Obtained Primarily Noninvasively

Determination of important anatomic variants (e.g., systemic venous anomalies) will help in planning of the procedure (e.g., site of vascular access) and will serve to minimize the number of angiograms needed to clarify the anatomy. One should avoid obtaining angiograms that provide redundant information already known from noninvasive studies (echocardiography, MRI) "just because we are there."

4.2.2 Position Patients Properly (Isocentered and Straight on the Table)

Having patients in the isocenter keeps the heart at the center of the field whichever angulated views are used. Prolonged fluoroscopy during changes in angiographic projection is therefore avoided. Another benefit of having the patient positioned correctly straight on the table is that cardiovascular structures can be consistently related to skeletal and tracheobronchial landmarks (e.g., fossa ovalis, the ductus arteriosus, etc.) with minimal trial and error or wasted fluoroscopy.

4.2.3 Use the Lowest Acceptable Frame Rate During Pulsed Fluoroscopy and Cine Angiography

Always use pulsed fluoroscopy, never continuous fluoroscopy. Be prepared to change the frame rates frequently during a case

depending on the type of structure that is being imaged (e.g., fast-moving vs. slow-moving; venous or arterial).

4.2.4 Do Not Use Fluoroscopy to Make Changes to the Patient/Table Position or Collimator/ Shields

Patients should be moved first to the approximate desired location, and then fluoroscopy should be used very brief to check the position, followed by further adjustment. This is especially important when patients need to be moved by an assistant during the case (e.g., to reposition the arms).

4.2.5 Remove Unnecessary Body Part (or Instruments) from the Field

A typical example of this is leaving the arms in the path of the beam. Leaving the arms in the field results not only in needless radiation exposure to the arms but also in an overall increase in radiation exposure to all the patient's tissues because the radiopaque arms drive the AEC to compensate with increase radiation output. The same can be said for the operator's hands and for any radiopaque instrument in the field.

4.2.6 Always Perform a Test Injection of a Small Amount of Contrast Material Using Fluoroscopy Prior to Acquiring an Angiogram

Fluoroscopy of the test injection can be useful to correct the angiographic projection prior to the actual angiogram, it can aid with determining the correct magnification mode (to prevent the

need for panning if the magnification is too high), and it can be stored and reviewed to help make these determinations.

4.2.7 Use the Lowest Acceptable Magnification Mode

The replay zoom features might be helpful in making measurements, at no radiation cost to the patients. Electronic magnification should be used sparingly, because of the substantial increase in the radiation dose it requires. Remember that excessive magnification requires panning to search for the structures of interest, leading to a further increase in radiation dose.

4.2.8 Use Collimators and Partial-Thickness Shields

Collimators are extremely beneficial overall in reducing the volume of tissue exposed to the primary beam and in reducing scatter; reducing scatter is, in turn, beneficial for reducing exposure to laboratory personnel and improving image contrast. As a general rule, the collimators should be visible within the field, and studies should not be performed with the collimator wide open.

4.2.9 Center the Region of Interest Correctly in the Field

The center of the field has the least amount of image distortion; therefore, an angiography should not intentionally be performed at the periphery of the field. Furthermore, bringing the region of interest to the center of the field allows for tighter collimation and less exposure of unnecessary patient tissues to X-rays.

4.2.10 Keep the Image Intensifier as Close to the Patient as Possible (and the X-Ray Tube as Far Away as Possible)

The farther the intensifier is from the patient, the higher the input dose and the scatter to the laboratory personnel. A distant intensifier also results in geometric magnification, which introduces geometric blur.

4.2.11 Use the Angiographic Projection That Reduces Operator Exposure Whenever Possible

For example, generally the right anterior oblique projection moves the X-ray tube away from the operator, while the left anterior oblique projection moves it closer.

4.2.12 Decrease Beam-On Time

Fluoroscopy must not be applied while discussing or contemplating the next maneuver. It is important to remember that if the eye is not on the screen, the foot should not be on the fluoroscopy pedal.

4.2.13 Remove Anti-scatter Grids When Catheterizing Small Children

A significant reduction in radiation dose is possible without compromising image quality.

4.2.14 Use X-Ray Stand Position Memory

Useful projections can be stored in the systems memory, allowing rapid return without the need for fluoroscopy to verify position.

4.2.15 Use Biplane Fluoroscopy, Roadmap, and Overlay Features

These features allow vessels of interest to be found with minimal trial and error.

4.2.16 Catheter Selection

An end-hole catheter is useful for selective, relatively small-volume injections by hand, such as into coronary arteries, aorto-pulmonary collaterals, and other small- or medium-sized arteries. Contrast injection into the cardiac chambers, main pulmonary trunk, or aorta should be made through a multi-side-hole catheter. Multiple side holes facilitate high contrast flow rates, high velocity of injection, and minimal catheter whip.

4.2.17 Contrast Delivery

In general, for anatomic definition, contrast should be delivered through the catheter as rapidly as possible, generally in 1 or 2 s. As a general rule, the volume of contrast recommended in each injection could be 1–1.5 cc/kg in a cardiac chamber or the aorta and 0.5–1 cc/kg in pulmonary branches (maximum volume of 30–40 cc per injection). A high flow rate is much important than volume for a good anatomic definition. Viscosity of contrast

medium is inversely related to temperature; therefore, warming the contrast medium may facilitate high-flow injection through lower profile catheters. Most catheter laboratories keep contrast in a warming cabinet, and injectors usually have a device to keep warm the contrast throughout the procedure [1, 2].

4.3 Contrast Media

The remarkably high tolerance of modern contrast media has been achieved through successive developments in chemical pharmacological technology. Nonetheless risks associated with contrast media (CM) have not been completely eliminated, and adverse reactions of varying degree continue to occur. Consequently, it is imperative that anybody administering contrast agents is familiar with the characteristics, indications, and potential side effects of these agents.

All intravascular iodinated CM are based on a tri-iodinated benzene ring. High-osmolar contrast media (HOCM) are the oldest agents. They are relatively inexpensive, but their utility is limited. They are monomers (single benzene ring) that ionize in solution with a valence of −1. Their cation is either sodium or meglumine. A major advance was the development of nonionic compounds. They are monomers that dissolve in water but do not dissociate in solution. Hence, with fewer particles in solution, they are designated low-osmolar contrast media (LOCM). The most recent class of agents are dimers that consist of a molecule with two benzenes (again, each with 3 iodine atoms) that do not dissociate in water (nonionic). These compounds are called iso-osmolar contrast media (IOCM) (Fig. 4.1). The toxicity of CM decreases as osmolality approaches that of serum. HOCM have an osmolality of 1,570 mosm/kg H_2O, while IOCM have an osmolality similar to serum at 290 mosm/kg H_2O.

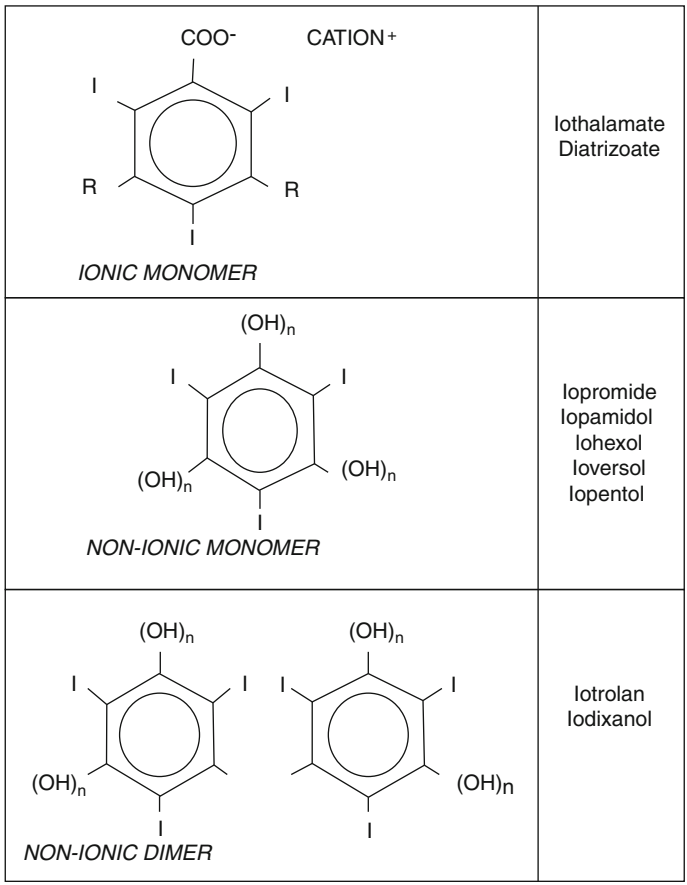

Fig. 4.1 Chemical structure of iodinated contrast agents and examples of contrast media

Since the purpose of these agents is to deliver iodine in sufficient concentration for imaging, the ratio of iodine atoms to particles in solution becomes important. The ratios are as follows: HOCM 5, LOCM 3.0, and IOCM 6.0. Currently used iodinated agents are cleared almost completely by glomerular filtration. With reduced renal function, there is excretion primarily in the bile and through the bowel. Circulatory half-life is 1–2 h, assuming normal renal function. In modern clinical practice ionic CM are rarely used in catheterization laboratories. IOCM have the lowest osmolality and more iodine atoms per molecule, producing the best contrast image. However, these are very expensive so the nonionic monomers (LOCM) remain the most widely used even in pediatric patients.

4.4 Contrast Reactions

4.4.1 Anaphylactoid Reactions

These are essentially anaphylactic reactions but are not initiated by an allergen-IgE complex. Indeed the pathway by which the mast cells become stimulated has not been clarified. The reaction can occur even the first time contrast is administered, and the severity is not dose related. Treatment is similar to other conventional anaphylactic reactions.

Patients who are at increased risk for anaphylactoid reaction may benefit from premedication. Such patients include those with asthma, allergies, or a history of a prior moderate or severe reaction to contrast. In this situation methylprednisolone and diphenhydramine are used.

4.4.2 Nonanaphylactoid Reactions

4.4.2.1 Chemotoxic, Organ Specific

Nephrotoxicity

Although institutional criteria vary, in general acute renal failure is defined when serum creatinine raises 25–50 % or 0.5–1 mg/dL. Serum creatinine peaks in 3–5 days but may be elevated as early as the first day. In young children creatinine levels may not be sensitive enough to detect renal failure; in these patients cystatin C levels or glomerular filtration values may be a more appropriate test. Risk factors for renal insufficiency induced by contrast are age >65 years, diabetes, end-stage liver disease, and severe congestive heart failure. Clinical manifestations are highly variable and may range from completely absence of urine to oliguria. Most effects are temporary and reversible. In mild cases, serum creatinine returns to normal in 2 weeks. When severe, dialysis may be necessary. The major preventive action against nephrotoxicity is to ensure adequate hydration. One possible protocol would be 0.9 % saline at 100 ml/h, beginning 6–12 h before and continuing 4–12 h after intravascular iodinated contrast medium administration. Pediatric infusion rates are variable and should be based on patient weight.

Cardiovascular Toxicity

Patients with underlying cardiac disease have an increase incidence and/or severity of cardiovascular side effects. Pulmonary angiography and intracardiac and coronary artery injections carry the highest degree of risk. Possible reactions include hypotension, tachycardia, and arrhythmias. More severe but uncommon reactions include congestive heart failure, pulmonary edema, and cardiac arrest.

Neurotoxicity

Iodinated contrast agents cause a change in the blood–brain barrier due to their hypertonicity. These risks are reduced when low- or iso-osmolar agents are used. Potential reactions include headache, confusion, seizures, altered consciousness, visual disturbances, and dizziness.

4.4.2.2 Vasovagal Reactions

These are characterized by bradycardia and hypotension. When a vasovagal reaction occurs, the patient should be put into the Trendelenburg position and atropine and IV fluid (saline or lactated Ringer's) administered if clinically necessary [3].

References

1. Justino H (2006) The ALARA concept in pediatric cardiac catheterization: techniques and tactics for managing radiation dose. Pediatr Radiol 36(Suppl 2):146–153
2. Lock JE, Keane JF, Perry SB (2000) Diagnostic and interventional catheterization in congenital heart disease. Kluwer Academic, Boston/Dordrecht/London
3. Robbins JB, Pozniak MA. Contrast media tutorial. https://www.radiology.wisc.edu/fileShelf/contrastCorner/files/ContrastAgentsTutorial.pdf