

# Joint Quality Improvement Guidelines for Pediatric Arterial Access and Arteriography: From the Societies of Interventional Radiology and Pediatric Radiology



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## PREAMBLE

THE membership of the Society of Interventional Radiology (SIR) Standards of Practice Committee represents experts in a broad spectrum of interventional procedures from both the private and academic sectors of medicine. Generally, Standards of Practice Committee members dedicate the vast majority of their professional time to performing in-

terventional procedures; as such they represent a valid broad expert constituency of the subject matter under consideration for standards production.

Technical documents specifying the exact consensus and literature review methodologies as well as the institutional affiliations and professional credentials of the authors of this document are available upon request from SIR,

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## METHODOLOGY

SIR produces its Standards of Practice documents using the following process. Standards documents of relevance and timeliness are conceptualized by the Standards of Practice Committee members. A recognized expert is identified to serve as the principal author for the standard. Additional authors may be assigned dependent upon the magnitude of the project.

An in-depth literature search is performed using electronic medical literature databases. Then a critical review of peer-reviewed articles is performed with regards to the study methodology, results, and conclusions. The qualitative weight of these articles is assembled into an evidence table, which is used to write the document such that it contains evidence-based data with respect to content, rates, and thresholds.

The Pediatric Interventional Radiology Standards Subcommittee members believed there were not sufficient data in the pediatric interventional radiology literature to generate thresholds for appropriateness, success, and complication. Even though we believed this would be quite important, very little has been

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written thus far to critically evaluate the extreme scope of pediatric intervention.

When the evidence of literature is weak, conflicting, or contradictory, consensus for the parameter is reached by a minimum of 12 Standards of Practice Committee members using a modified Delphi consensus method (Appendix A) (1). For the purposes of these documents, consensus is defined as 80% Delphi participant agreement on a value or parameter.

The draft document is critically reviewed by the Standards of Practice Committee members, either by telephone conference calling or face-to-face meeting. The finalized draft from the Committee is sent to the SIR membership for further input/criticism during a 30-day comment period. These comments are discussed by the Standards of Practice Committee, and appropriate revisions made to create the finished standards document. Prior to its publication the document is endorsed by the SIR Executive Council.

## PEDIATRIC ARTERIOGRAPHY: GENERAL CONSIDERATIONS

The modern angiography suite must meet many requirements (2–4). These desirable room characteristics are listed in Table 1. Rapid imaging rates and three-dimensional arteriography can greatly facilitate certain examinations, especially planning of complex interventional procedures (5). All individuals involved in the performance of the angiography procedure must be well trained, experienced in pediatric patients and procedures, and comfortable with their surroundings.

## RADIATION PROTECTION

The potentially harmful effects of ionizing radiation on the patient and the personnel performing the arteriographic examination mandate policies and guidelines to help protect everyone involved. The pediatric patient is more sensitive to radiation effects than an adult (6–8), and the “ALARA” concept (“as low as reasonably achievable”) is extremely useful in planning and implementing methods to reduce dose (6,9). There has been an entire supplement published in *Pediatric Radiology* on this topic, including specific issues and concerns in the pediatric interventional

**Table 1**  
**Desirable Angiography Suite Characteristics**

Easy accommodation of personnel needed to perform the arteriography procedure
Easy access to patient permitted
Monitoring equipment clearly visible from all angles
Anesthetic and electrical equipment easily accessible and clearly marked
“Crash cart” always maintained and visible
State-of-the-art fluoroscopy equipment
Roadmapping essential
Biplane imaging preferred for neurointerventional and complex interventional procedures
Ability to review studies inside/outside suite
Contrast medium injector permits easy movement and ready access to patient
US imaging readily available
Appropriate transducers for varying patient size
Doppler imaging capability

suite (4,10–20). Principles regarding patient protection in diagnostic radiology have been summarized elsewhere (6).

Methods of reducing pediatric radiation during arteriography are listed in Table 2. Total fluoroscopy exposure and arteriography run times must be minimized. Progressive pulse fluoroscopy, last image hold, use of filters, appropriate shielding (including gonadal protection), and optimal coning all help in reducing patient exposure, with reduction in distance between the image receptor and the patient allowing for reduction in scattered radiation. Removal of the grid is important when imaging neonates and small infants. If magnification is required, the consequent significant increase in radiation dose should be remembered, with consideration of digital magnification instead.

Similar attention should be paid to personnel dose reduction. Radiation protection is mandatory. Comfortable and lightweight radiation protection aprons, thyroid shields, and eyewear are available from multiple vendors, as are lead or lead-equivalent gloves. Ceiling-mounted floating shields, mobile floor shields, and patient-applied lead or lead-equivalent pads allow for dose reduction to the angiographer. As arteriography usually delivers the highest radiation exposure to patient and personnel of any diagnostic study (9), everyone should attempt to leave the angiography suite during arteriographic runs. At the very least, those not involved in the performance of the angiography procedure should be protected behind standing leaded shields. Remembering the inverse square law (ie, radiation dose decreases

exponentially with distance from the source) is also very important for all personnel. Equipment should be serviced regularly, with visible dosimetry monitoring strongly encouraged, and recorded for each patient in the medical record. All personnel should wear dosimeters; these should be at the level of the thyroid gland, outside lead protection, to allow radiation dose monitoring in accordance with local regulatory requirements.

## PREARTERIOGRAPHIC EVALUATION AND PREPARATION

A regimented protocol for patient assessment must be followed before any arteriographic procedure. This includes careful review of the indications for the study requested, as well as patient-specific information pertinent to the study, with special attention to history and physical examination findings. Previous laboratory and imaging results pertinent to the study should be reviewed. Appropriate discussions with consultant physicians help determine the goals of the arteriographic procedure. An open and comprehensive conversation with the patient and/or family (ie, informed consent) regarding indications for arteriography, relevant details of the procedure, potential risks and benefits, and expected outcomes is mandatory. A similar discussion of the elements of sedation, analgesia, and anesthesia is also required and should be documented in the medical record.

Specific issues, such as allergies, renal function, coagulation profile and bleeding tendencies, current medications, and antibiotic prophylaxis must

be considered. The need for clotting studies before most routine diagnostic arteriographic procedures is currently under review; however, if there is a history of known blood dyscrasias, easy bruising, or medical conditions or medications known to affect coagulability, International Normalized Ratio, partial thromboplastin time, and platelet count should be evaluated. It is important for the pediatric interventionalist to be aware that laboratory values vary depending on the age of the patient (21) and varying techniques of local laboratories. Neonates (age  $\leq 28$  d) usually have prolonged parameters but are generally hypercoagulable. Caution should be exercised when the coagulation parameters are prolonged or when the patient has a history of easy bruising or bleeding. General guidelines are that elective procedures can be performed safely with a platelet count greater than  $50,000/\mu\text{L}$ , prothrombin time less than 18 seconds, partial thromboplastin time less than 32 seconds, and an International Normalized Ratio less than 1.2, with an International Normalized Ratio less than 1.5 preferred for urgent cases. Emergency cases are evaluated on a case-by-case basis. Although some coagulopathies may correct spontaneously, more rapid correction can be achieved through use of oral vitamin K, administration of fresh frozen plasma, and platelet transfusion. Specific guidelines for correction of pediatric bleeding abnormalities have been published (21). Preprocedural antibiotic prophylaxis is rarely indicated in children undergoing arteriographic procedures. There may be exceptions, including children with cardiac shunts, those with suspected infection in whom foreign bodies such as embolization coils will be implanted, and end-organ embolization procedures with a potential for abscess formation.

A physical examination relevant to arteriography is necessary, including cardiopulmonary and vascular assessment, with evaluation and documentation of all peripheral pulses and recording of the child's height and weight. Choice and route of sedation must be decided in patients who require sedation support. Although select situations and patients may require only local anesthetic administration, very young patients and those undergoing lengthy diagnostic and interventional procedures, including those requiring intermittent breath holds, will likely require more

**Table 2**  
**Methods to Reduce Patient Radiation Exposure**

Minimization of total fluoroscopy exposure and arteriography run times Progressive pulse fluoroscopy Last image hold Use of roadmapping Use of filters Appropriate shielding (including gonadal protection and other regions) Optimal coning/collimation Reduction in distance between the image receptor and the patient (reducing scattered radiation) Optimally increase source-to-skin distance Removal of grid when imaging neonates and small infants Use of digital magnification Optimize patient cooperation (eg, appropriate sedation, immobilization, distraction)
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aggressive sedation, and possibly general anesthesia with intubation. When the goal of arteriography includes diagnosis or treatment of small vessels or involves complex anatomy, use of paralytic agents or other immobilization aids, respiratory control, and intravenous glucagon for evaluation of splanchnic vessels may significantly improve the quality of the examination, thereby reducing the need for additional arteriography. Topical anesthetic creams such as EMLA (lidocaine/prilocaine; Astra Zeneca, Wilmington, Delaware), Maxilene (liposomal lidocaine 4% cream; RGR, Windsor, Ontario, Canada), and Ametop (tetracaine HCl; Smith & Nephew, London, United Kingdom) are useful adjuncts for patients undergoing conscious sedation to lessen the painful sensation caused by local anesthetic agent infiltration. A list of the more commonly used medications in the angiography suite is provided in **Table 3**. As the topic of sedation in the setting of the pediatric interventional suite is too broad for this guideline, it will not be discussed further.

Maintaining the appropriate homeostatic and monitoring environment during the arteriographic procedure is of paramount importance. Young children, especially those younger than 2 years of age, are very susceptible to ambient temperature changes. Therefore, temperature monitoring is recommended. Measures that can aid in maintaining appropriate temperature in the young child are listed in **Table 4**. Warming of fluids being administered (including contrast medium) can be helpful, especially in small children and babies. Although urinary catheters should be considered for lengthy procedures or

for procedures for which pelvic imaging is important, in-and-out catheterizations may also allow for increased patient comfort in the postprocedural setting. Patient size-specific leads and probes for routine electrocardiography, blood pressure, and respiratory monitoring are placed, with proper padding of pressure points to minimize nerve palsies (2,9,22). Appropriate patient immobilization for optimizing image quality and minimizing arteriographic runs is also important.

## CONTRAST MEDIA

Many different choices for contrast media are commercially available. Although iodine-based contrast media are the mainstay of pediatric arteriography, other contrast agents, such as gadolinium or carbon dioxide gas, may be used in select circumstances (23). Osmotoxic effects of iodine-based contrast media or gadolinium correlate with physiologic consequences such as perceived heat and discomfort (24). High-osmolar contrast media are five to eight times the normal blood osmolality ( $300 \text{ mOsm/kg}$  of water) and are no longer used in arteriography. Low-osmolar contrast media and isoosmolar contrast media offer a significant reduction in osmolality (6,9). Low-osmolar contrast medium, commonly of the nonionic monomeric variety ( $300\text{--}350 \text{ mgI/mL}$ ), are most commonly used for pediatric arteriography as they offer improved patient comfort and allergy profile, with a reduction in nephrotoxicity and osmotic load (24–27). A discussion of contrast agent-related complications follows later in this article.

**Table 3**  
**Common Medications Used During Arteriography**

Medication	Dose	Indication
Nitroglycerin (glyceryl trinitrate)	1–3 $\mu\text{g}/\text{kg}/\text{dose}$ IA, repeated up to 3 times	Treatment of vasospasm
Heparin	75–100 IU/kg IV	Prevent arterial thrombosis in patients <15 kg
Protamine agent	10 mg IV per 1,000 IU heparin*	Heparin reversal
Glucagon	20–300 $\mu\text{g}/\text{kg}$ IV/IA in neonates; 20–100 $\mu\text{g}/\text{kg}$ , max 1 mg	Decreases bowel motility
Papaverine	1 mg/kg IA	Treatment of vasospasm
Lidocaine	0.5 mL/kg (5 mg/kg) 1% (without epinephrine) 0.7 mL/kg (7 mg/kg) 1% (with epinephrine)	Local anesthesia
Bupivacaine	1 mL/kg (2.5 mg/kg) 0.25%	Local anesthesia

Note.—IA = intraarterial; IV = intravenous.

\* Dosing is often adjusted allowing for the half-life of administered heparin dose.

**Table 4**  
**Warming Strategies for Procedures in Small Children**

Conservation
Increase room temperature
Warm blankets
Plastic (ie, “cling”) wrap
Convection
Radiant heat from warming lamp
Warm air flow*
Conduction
Warm saline solution bags
Chemical warming blanket†

\* eg, Bair Hugger; Arizant, East Prairie, Minnesota.

† eg, TransWarmer; Cooper Surgical, Trumbull, Connecticut.

**Table 5**  
**Relative Contraindications to Arteriography**

Contrast agent allergy
Elevated coagulation parameters
Renal insufficiency/failure
Inability to tolerate contrast volume load (eg, congestive heart failure)
Active large-vessel vasculitis
Severe uncorrected hypertension
Known collagen vascular disease, predisposing to increased risk of vascular injury or thrombosis
Ehlers–Danlos syndrome, especially type IV
Pseudoxanthoma elasticum
Homocystinuria
Infection at planned site of vascular access
Sepsis
Pheochromocytoma

such as known anaphylaxis to conventional contrast medium can be addressed if the patient’s medical condition leaves no other options. A list of contraindications is provided in [Table 5](#).

## ARTERIAL ACCESS AND ARTERIOGRAPHY

Obtaining vascular access is often the most challenging aspect of pediatric arteriography. Many unique issues with respect to needles, wires, and catheters are created by the wide range in patient size. There must be careful thought regarding the preferred and backup sites for arterial access, as well as optimizing patient preparation and positioning, especially in young infants.

Some key differences exist regarding obtaining arterial access between children and adults. Pediatric vessels are often superficial, especially in the neonate or young infant, with the arteries much straighter and having very little or no intrinsic vascular disease. Pediatric vessels tend to occlude more easily, primarily because of the larger catheter-to-vessel ratio, especially in children weighing less than 15 kg, coupled with a greater occurrence of vasospasm ([22,34,40](#)) and dissection ([9](#)). These issues will be discussed further later.

Much has been written on how to obtain pediatric vascular access ([2,3,6,9,22,34,37,41–50](#)). The standard arterial site for most arteriography procedures is the common femoral artery. Uncommonly, other sites and approaches for arterial access may be required, including axillary, brachial, and umbilical access. Direct carotid or vertebral arterial puncture is rarely indicated but may be necessary in very complex neurointer-

## ARTERIOGRAPHY

### Indications

Pediatric vascular disease is extremely varied. It includes congenital and acquired disorders of every major organ system. The most common indications relate to cerebrovascular pathologic processes, renovascular hypertension, visceral arteriography for liver/bowel or portal pathologic processes, and arteriography in the setting of trauma ([2,28–35](#)). Advances in noninvasive vascular modalities such as magnetic resonance (MR) angiography, computed tomographic (CT) angiography, and ultrasound (US) have increased the number of conditions that can be evaluated without catheter arteriography. However, diagnostic catheter arteriography continues to be the gold standard modality for many conditions. In addition, advancements in

pediatric interventional techniques have increased the ability for catheter-directed arterial interventions, such as peripheral embolization, angioplasty, medication delivery, and endoneurovascular procedures ([3,9,36–39](#)). This has led to an increasing percentage of arteriographic procedures being done for therapeutic considerations rather than diagnostic indications.

### Contraindications

It is mandatory that a discussion with the patient and/or family and referring physicians takes place. Arteriography is usually contraindicated if a diagnosis and therapeutic choices can be based on information obtained in a noninvasive manner. Other contraindications do exist; however, even issues



ventional procedures (2). Surgical access may occasionally be required, especially in planned aortoiliac device implantation procedures. As the umbilical artery is usually patent for as long as 5 days after birth, this access may be an excellent alternative to conventional access in the neonate or premature infant as it can accommodate larger sheath/catheter sizes, thereby sparing the peripheral vasculature of potential access-related complications (2,9,41,51). A small test injection of contrast medium can determine its patency, especially if access beyond 1 week is considered. Diagnostic catheters 3–4 F in size or 4–5-F sheaths or delivery catheters can be used. After the angiogram has been obtained, hemostasis can be achieved with use of umbilical tape.

Traditionally, percutaneous vascular access has been achieved by vessel palpation. This can sometimes be quite challenging, especially in the young child or infant, or in the markedly obese child. Direct US visualization has revolutionized arterial access, and should be considered for use in all patients, not just those with a history of multiple previous catheterizations, known difficult access, or reduced pulses. High-frequency linear transducers have been developed by almost all US equipment manufacturers.

All efforts should be made to make the puncture below the inguinal ligament. The increasing use of US can allow for determination of the point of bifurcation of the common femoral artery into the superficial femoral and profunda femoris arteries. Although infiltration of local anesthetic agent is recommended for patient comfort, its administration should not obliterate the pulse. The dermatotomy should be created carefully to avoid injury to the vasculature that may lie immediately beneath the skin. Double-wall access technique can be used without significant complications unless anticoagulation is being considered, in which case efforts should be made to attempt single-wall access. Active aspiration on the needle is not usually required for arterial access. The needle system should be flushed to clear potential clot or tissue after each unsuccessful pass. After good blood flow is obtained, guide wire advancement should be effortless and monitored under fluoroscopy. Floppy-tipped nitinol wires are excellent in achieving micropuncture access, whereas

larger wires with atraumatic tips, such as the Bentsen wire (Cook, Bloomington, Indiana), are good choices with 0.035-inch compatible access needles. Mild manipulation of the needle may aid in guide wire passage if resistance is encountered. Sometimes, a test injection of contrast medium may help in deciding if arterial access has been achieved. Roadmapping to negotiate past stenoses or obstructions may occasionally be necessary. Failed attempts at access require holding for at least 1–2 minutes for small-gauge needles. Holding as long as 5 minutes may be necessary if an 18-gauge needle is used. All attempts at manual hemostasis should be done gently, avoiding prolonged occlusive pressure to ensure maintenance of perfusion to the distal extremity, and to minimize the possibility of thrombosis of the access artery.

Although many different needle/wire/catheter combinations can be used, the smallest appropriate needle and catheter system should be selected. The choice of access needle is completely dependent on personal experience, as some angiographers prefer flexible plastic or Teflon venipuncture cannulas whereas others prefer rigid metal cannulas. Potential advantages of flexible cannula techniques include a theoretically reduced risk of intimal injury, guide wire kinking, or wire trauma; however, their use is more difficult to master (44,48). A potential advantage of dedicated vascular cannulas is their larger internal diameter versus venipuncture needles of the same gauge (48). Regardless, small-gauge needles are essential for access. Micropuncture systems in 4- and 5-F sizes are readily available and allow easy conversion of 0.018-inch access to 0.035- or 0.038-inch guide wire systems.

Dilators can minimize trauma related to catheter or sheath placement after access has been obtained. Although no consensus was reached, expert opinion advocates routine use of vascular sheaths, especially if several catheter exchanges, multiple manipulations, or interventional procedures are expected (3,9,22). Potential benefits include maintenance of vascular access, reduced spasm, and precise torque of catheters. These must be weighed against the intrinsic drawback of larger access resulting from sheath placement (2,3). Guide wire choice depends as much on operator preference as it does equipment

specifications. Regardless of technical variations in obtaining arterial access, all efforts should concentrate on safe and expedient access, with minimization of manipulation and force.

Diagnostic arteriography catheters also vary tremendously (52). The smallest catheter that can accomplish the objectives of the study should be used. Some angiographers still steam-shape straight catheters to achieve their desired terminal curve, with slight exaggeration of the curve often necessary as there is a tendency to lose some of the curvature in the temperature of the arterial circulation (22). Most angiographers now prefer preshaped catheters. These can be braided or nonbraided, and can have varying degrees of torque control and flow capacity (6). Dedicated pediatric-length catheters are now becoming available as adult-type preshaped catheters may not have the appropriate configuration or curvature for pediatric arteriography. In most diagnostic cases, 4-F systems can be used for patients larger than 10 kg, and 3-F catheters for those smaller than 10 kg (34,53). If microcatheters are required, these can be advanced directly through 3- and 4-F arterial sheaths, or coaxially through catheters with an appropriate internal diameter (2).

Intraoperative systemic heparinization can prevent vascular thrombosis and its use is well accepted, especially in arteriography performed in infants smaller than 10–15 kg (2,3,22,34,40). This is typically administered as a 75–100-IU/kg intravenous bolus dose after vascular access is obtained. Some angiographers use activated clotting time measurements to ensure appropriate anticoagulation, such as in neurointerventional procedures or lengthy peripheral interventional cases (41). Pharmacologic reversal of systemic heparinization with use of intravenous protamine sulfate is rarely necessary (22).

In the arterial circulation, pediatric arteriography is very similar to that performed in an adult. Lack of vessel tortuosity makes intraarterial navigation quite straightforward. Ideally, catheter advancement should be preceded by contrast medium administration, saline solution flush, or a wire. As the younger child and infant are prone to volume overload and contrast agent nephrotoxicity, volume of injected contrast medium and flush must be carefully monitored. Also, tailoring the size of the

syringes used during the case to the size of the patient can aid in minimizing inadvertent phlebotomy or fluid overload. Consideration should be given to warming contrast media in cases in which large volumes are expected to be used, especially in small children. Contrast agent dose should be limited to 4–5 mL/kg for neonatal arteriography, whereas 6–8 mL/kg should be regarded as the maximum volume for pediatric patients beyond this age (2,9,41). Larger volumes can be used during longer procedures if small incremental injections are performed and there is optimal patient hydration. Aspiration of contrast medium occupying the “dead space” of a catheter can extend the amount of contrast medium administered for diagnostic purposes while minimizing waste. Standard projections as per adult imaging are used for most arteriographic runs. Volume of injection will vary depending on target object to be imaged. Guidelines for specific vessel injection rates are given in **Table 6** (22,50,54–57).

Although many access closure devices exist for adult arteriography, there is little literature to support their use in the pediatric patient. Generally speaking, use of closure devices is not recommended, especially in infants and small children, because of a higher risk of local complications, such as stenosis or arterial occlusion. In selected settings, puncture tract sealing techniques currently being developed may hold promise (58).

## COMPLICATIONS

Although complications are not common during pediatric diagnostic arteriography, they can still occur, primarily in patients smaller than 15 kg. These can sometimes be quite serious (44). However, the rate of complications has decreased over the years because of many factors, including improvements in digital subtraction arteriography and guide wire and catheter technology. Prompt recognition and treatment of complications remains of utmost importance.

Complications can be directly procedure-related (ie, puncture site or catheter-related complications) or systemic. The overall incidence of vascular complications in the adult population is less than 1% (59,60). In the pediatric population, the risk is variable and may be as high as 7%–10% in patients younger than 1 year of age (61,62). However, the

**Table 6**  
**Injection Parameters by Location and Patient Weight\* (21,55,56)**

Artery	Patient Weight (kg)			
	<10	10–20	20–50	>50
Aorta	†	5–10 for 8–15	10–20 for 20–40	20–25 for 25–50
Celiac	†	2–3 for 10–20	3–5 for 15–30	5–8 for 30–60
Splenic	†	2–3 for 10–15	3–5 for 15–20	5–8 for 20–50
Hepatic	†	2–3 for 5–10	3–5 for 10–15	5–8 for 15–25
SMA	†	2–3 for 10–15	3–5 for 15–30	5–8 for 30–50
IMA	†	†	1–3 for 6–9	2–3 for 10–15
Renal	†	2–4 for 3–5	3–5 for 6–9	5–8 for 10–15
Adrenal	†	†	†	†
Subclavian	†	2–3 for 4–6	3–4 for 6–15	5–8 for 15–25
Common carotid	†	2–3 for 3–5	4–6 for 5–10	6–8 for 10–15
Internal carotid	†	1–2 for 3–5	2–4 for 5–8	4–5 for 6–10
External carotid	†	†	†	2–3 for 6–9
Vertebral	†	†	2–5 for 4–6	4–7 for 6–9

Note.—Values presented as rates in mL/sec for total volumes in mL. No consensus is available on injection rates or volumes, and these figures serve as suggested reference ranges only. Improvements in imaging, contrast agents, and injector pumps, as well as use of medications (eg, bowel paralytic agents or vasodilators), may result in significant variability from institution to institution. Pump injections are often required for arteriography performed in regions requiring high flow rates (eg, aorta); however, many pediatric angiographers prefer hand injections for selective arteriography, or in arteriography in neonates and small infants, to maximize control of arterial bed opacification and minimize contrast agent reflux or excessive injection rates. IMA = inferior mesenteric artery; SMA = superior mesenteric artery.

\* Lower rates and volumes are recommended in each weight category for those toward the lower limit of the range, whereas higher rates and volumes are recommended for those toward the upper limit of each weight category. Arterial phase imaging of 3–4 frames per second is suggested, whereas injections imaging into venous phase (eg, splenoportography) will likely require greater contrast medium volumes and slower imaging (ie, down to 1 frame per second).

† Hand injection recommended.

majority of quoted figures for vascular complications are obtained from pediatric cardiac catheterization literature because of the lack of reported pediatric interventional radiology series. Access complications are likely significantly less common within the pediatric interventional radiology population compared with classical literature values given advancements in technology and the increasing use of US guidance.

Complications at the site of access are predominantly vascular and are primarily in the neonate or infant population (60,62,63). These continue to be the most common adverse event following arteriography (62). Puncture site complications include local hematoma, dissection, thrombosis/occlusion, pseudoaneurysm, and arteriovenous fistula formation. The incidence of hematoma varies from 0.3% to as high as 25% when arterial interventions are performed in patients smaller than 15 kg (64,65). Arterio-

venous fistulas occur more frequently with low groin punctures, with which there is a higher likelihood of simultaneous arterial and venous puncture (60). In their study of 1,674 catheterization procedures in 1,431 patients, Lin et al (64) demonstrated that the risk of pseudoaneurysms and arteriovenous fistulas was 0.3% overall, with an increased risk in those younger than 3 years of age, when sheaths 6 F in size or larger were used and when the number of arteriographic procedures exceeded three. Most access site complications are asymptomatic, and approximately 80% close spontaneously within 3 months.

Although cellulitis at the access site has been described, true infection is rare, and antibiotic prophylaxis is not necessary in most procedures (66). Access should always be below the inguinal ligament to minimize retroperitoneal hematoma formation. Axillary or brachial arterial access has an increased

**Table 7**  
**Pediatric Contrast Agent Allergy: Oral Premedication Protocol**

Medication	Dosage (mg/kg)	No. of Doses	Time Until Procedure (h)	Timing	Maximum Dose (mg)
Prednisone	0.5	3	13	13, 7, and 1 h before procedure	50 per dose
Diphenhydramine	1.25	1	1	1 h	50

risk of complication as a result of the smaller vessel caliber, as well as greater difficulty in achieving hemostasis after the angiography procedure. The risk of vascular access is proportional to sheath size, number of examinations, and patient age. US-assisted arterial access guidance decreases the number of attempts required and lessens puncture site complications.

The risk of thrombosis is higher in general within the pediatric population, and may be as high as 8%–10% (40,62,67–70). The risk increases to 16% in those smaller than 15 kg (71) and may be as high as 39% when arterial interventions are performed with larger sheaths (65). The cause is usually vasospasm, especially in smaller patients. As return of palpable pulses can be a false indicator of vessel patency (as a result of vigorous collateral vessel reconstitution of distal pulses), rapid determination of vasospasm versus access site thrombosis may be made by duplex US (72).

Nitroglycerin at a dose of 1–3  $\mu\text{g}/\text{kg}$  can be administered intraarterially to treat vasospasm, especially before sheath removal (2). In patients at higher risk of developing access site thrombosis, systemic heparin at a dose of 75–100 IU/kg during arteriography is recommended. Many authors have suggested various treatment regimens if arterial thrombosis does occur (2,9,34,40,41). The patient's affected limb should be kept warm (eg, wrapped in warm cloth), with close observation for 2–4 hours. Systemic heparinization is recommended if distal pulses have not returned, with a bolus of 75–100 IU/kg administered intravenously, and heparin infusion to maintain a partial thromboplastin time approximately twice normal. This is typically continued until pulses return, or for 24 hours. Insufficient data are available to provide a consensus opinion regarding the use of thrombolytic agents; however, several authors report their use to restore arterial patency in situations in which

pulses are still absent after a 24-hour period (9,34,40,73). However, fewer than 10% of pediatric patients have future claudication or limb length discrepancy in the setting of asymptomatic persistent femoral arterial occlusion, because of the development of a rich collateral network (60).

Catheter-related complications are less common as a result of improvements in catheter and guide wire technology. In the adult population, the reported rates are less than 0.5% (74).

Pettersson et al (53) reported inadvertent embolization during pediatric cerebral arteriography occurring at the same frequency as in adults, at 0.9%, but with milder consequences. To our knowledge, there are no current studies demonstrating the risk of embolization during pediatric arteriography. The risk is clearly less than in the adult population as a result of the absence of atherosclerotic disease. Others have reported an even lower rate of major and minor complications (75). However, catheter-related complications underscore the need for meticulous technique and vigilance during arteriography.

Systemic complications such as hypoglycemia and hypothermia are more common in the neonatal and premature group. Measures to prevent hypothermia are listed in Table 2. Hypoglycemia can be treated with a bolus of 5%–10% glucose through a peripheral intravenous catheter, with higher concentrations used centrally (41). Other issues such as nausea and vomiting occur in less than 5% of cases, as in the adult population.

Deep intravenous sedation and general anesthesia are more commonly used within the pediatric population because of the patient's inability to cooperate or in anticipation of lengthy or painful procedures. General anesthesia may be preferred in cases in which airway management is an issue or in patients in whom previous attempts at sedation have failed. Moderate sedation

can be performed under the supervision of medical personnel trained in pediatric sedation, whereas deep sedation or general anesthesia must be performed under the supervision of an individual credentialed to perform deep sedation. Although the risks of general anesthesia are low, they can be significant (34,76). The majority of complications seen with general anesthesia are minor, with postoperative nausea and vomiting the most common. Oral trauma, such as hoarseness and sore throat, is relatively common, with dental trauma rare. Cardiorespiratory complications such as respiratory depression, hypertension, arrhythmia, myocardial infarction, and stroke are extremely rare. The risk of death is less than 1 per 100,000 cases (77). In experienced hands, serious adverse events during pediatric sedation are rare. Less adverse events such as stridor, laryngospasm, wheezing, or apnea occur in 1 in 400 cases. Bag-mask ventilation and oral airway insertion are required in 1 in 200 cases (78).

Allergic (ie, idiosyncratic) reactions to contrast media occur in fewer than 3% of cases in the adult population and are considered rare in children (22,79), with a recent article by Dillman et al (80) reporting an incidence of 0.18% of acute allergic-like reactions in 11,306 children receiving intravenous low-osmolar contrast medium. Reactions are similar and include urticaria, pruritus, angioedema/laryngeal edema, bronchospasm, and shock. The risk of a reaction is five times greater in asthmatic patients (81). Reactions are dose-independent and unpredictable, and are less common when low-osmolar contrast medium is used (82). There is no value in administering a test dose of contrast medium (83,84). Prophylaxis should be considered when there is a clear history of significant allergy, with many regimens existing (22,41,82,83,85). Guidelines for contrast agent allergy prophylaxis are provided in Table 7.

The risk of contrast agent-induced



**Table 8**  
**Risk Factors for Contrast Agent-  
 induced Nephrotoxicity**

Dehydration/decreased effective arterial volume
Preexisting renal insufficiency
Congestive heart failure (reduced ejection fraction)
Diabetes
Concurrent use of nephrotoxic medications (eg, aminoglycosides)
High contrast agent dose
High-osmolar contrast agent
Vascular disease
Nephrotic syndrome
Cirrhosis
Short contrast agent dose interval/repeated doses

nephropathy has been evaluated by many authors, but mainly within the adult population, and is variable depending on its definition (24,84,86–92). The risk of contrast agent-induced nephropathy is usually less than 7% and is greatest (as high as 25%) in patients with certain risk factors (see Table 8) (85). The main risk factor is preexisting renal impairment, primarily when the cause is diabetes mellitus. Other risk factors include dehydration, congestive cardiac failure, hyperuricemia, use of nephrotoxic drugs, hypertension, and proteinuria. The true risk of contrast agent-induced nephropathy within the pediatric population is currently unknown. The type of contrast agent used and its dose are also important factors. The risk of nephrotoxicity is markedly less with the use of low-osmolar contrast medium and may be even further reduced with the use of isoosmolar agents (85). Carbon dioxide arteriography is an alternative contrast agent in children; however, the literature on its use in the pediatric setting is limited (23). The nephrotoxic effect of contrast medium is dose-dependent, with larger doses having greater effect. Generally, contrast agent doses of 4–5 mL/kg in neonates and 6–8 mL/kg for the remainder of the pediatric population are recommended to minimize the risk of nephrotoxicity (2,9,41). In addition, because of advances in image acquisition and roadmapping technology, dilution of contrast medium (ie, to half strength) can offer significant dose reduction without compromising image quality. However, larger doses can, be used for

procedures of longer duration, in emergency settings, as well as for other selected clinical indications.

Adequate preprocedural hydration may help in minimizing nephrotoxicity (24,91,93). In lower-risk cases and for outpatients, oral or intravenous preprocedural hydration can be administered, followed by intravenous saline solution infusion for 6 hours after the procedure. Sodium bicarbonate infusion has shown to be of benefit in the adult population (94) but has not yet been validated in the pediatric population.

Other than thromboembolic complications, other adverse events during arteriography are rare (84,95–101). Seizures and transient cortical blindness occur in 0.2% and 0.3%–1% of cerebral angiography procedures, respectively, and are self-limited in almost all cases (84,95,97,99). Transient encephalopathy/global amnesia, although rare, has also been described (84,98–100).

### ALTERNATIVES TO CONVENTIONAL ARTERIOGRAPHY

As mentioned previously, advances in US, CT, and MR imaging technology have given the potential for noninvasive vascular imaging to provide anatomic and physiologic information that was once obtained only through catheter arteriography (102–122). Evaluation using MR angiography and CT angiography has replaced many traditional indications for catheter arteriography. This has led to less radiation exposure to the child and, in the case of MR imaging, may help avoid potentially nephrotoxic contrast media (123,124). However, it was recently determined that administration of chelated gadolinium contrast agents in patients with renal failure can result in potentially fatal nephrogenic systemic fibrosis (125). It is currently thought that loss of chelation results in circulation of toxic elemental gadolinium resulting in nephrogenic systemic fibrosis. Recommendations for administration of gadolinium-based contrast medium in cases of renal failure is currently being reevaluated.

New techniques are continually being developed. MR digital subtraction arteriography may be helpful in assessing head and neck lesions (126), and time-resolved MR angiography allows for noninvasive temporal vascular imaging, thereby providing important flow infor-

mation previously obtained only with catheter arteriography (119,122). Improvements in coil design and higher-field MR units (ie,  $\geq 3.0$  T) also have significantly improved spatial resolution of vascular imaging (127).

The role of CT angiography is also increasing in importance (128,129). Unique technical issues such as contrast agent volume, injection rates, sedation, radiation dose, breath-holding factors, and timing of scan initiation must be addressed to successfully perform pediatric CT angiography (130,131). Extremely rapid image acquisition can be achieved with the use of multidetector helical technology. This can provide isotropic volumetric data, allowing three-dimensional data sets with amazing detail while potentially decreasing sedation needs by decreasing the time needed to scan the patient (132).

Despite these advances, there are still some drawbacks to these noninvasive technologies. Because of the tremendous variation in pediatric patients, CT angiography and MR angiography must be tailored to the size and physiology of the child being examined. These noninvasive imaging techniques are still plagued by their inability to resolve small vessels (113). CT angiography (especially multidetector CT angiography) is limited in the setting of serial evaluation as a result of attendant radiation exposure issues, while MR imaging/MR angiography remains expensive and time-intensive.

### SUMMARY

Pediatric arteriography is an extremely important method of evaluating the vascular system. Advances in imaging, catheters and wires, contrast agents, and other techniques now allow for better diagnostic abilities, and have expanded the therapeutic possibilities in pediatric vascular intervention. Although noninvasive modalities such as US, CT angiography, and MR angiography have become increasingly important in pediatric vascular imaging, many indications remain for catheter arteriography. A multidisciplinary approach, a firm understanding of the similarities and differences between adult and pediatric arteriography, and meticulous technique ensure the safety of the pediatric patient when performing pediatric arteriography.



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## APPENDIX A: CONSENSUS METHODOLOGY

Reported complication-specific rates in some cases reflect the aggregate of major and minor complications. Thresholds are derived from critical evaluation of the literature, evaluation of empirical data from Standards of Practice Committee members' practices, and, when available, the SIR HI-IQ System national database.

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The clinical practice guidelines of the Society of Interventional Radiology attempt to define practice principles that generally should assist in producing high quality medical care. These guidelines are voluntary and are not rules. A physician may deviate from these guidelines, as necessitated by the individual patient and available resources. These practice guidelines should not be deemed inclusive of all proper methods of care or exclusive of other methods of care that are reasonably directed towards the same result. Other sources of information may be used in conjunction with these principles to produce a process leading to high quality medical care. The ultimate judgment regarding the conduct of any specific procedure or course of management must be made by the physician, who should consider all circumstances relevant to the individual clinical situation. Adherence to the SIR Quality Improvement Program will not assure a successful outcome in every situation. It is prudent to document the rationale for any deviation from the suggested practice guidelines in the department policies and procedure manual or in the patient's medical record.