Digital angiography in the pediatric patient with congenital heart disease: comparison with standard methods

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ABSTRACT  Digital subtraction angiography (DSA) permits high-resolution cardiac imaging with relatively low doses of contrast medium and reduced radiation exposure. These are potential advantages in children with congenital heart disease. Computer-based DSA (30 frames/sec) and conventional cutfilm angiography (6 frames/sec) or cineangiography (60 frames/sec) were compared in 42 patients, ages 2 months to 18 years (mean 7.8 years) and weighing 3.4 to 78.5 kg (mean 28.2 kg). There were 29 diagnoses that included valvular regurgitant lesions, obstructive lesions, various shunt abnormalities, and a group of miscellaneous anomalies. For injections made at a site distant from the lesion and on the right side of the circulation, the mean dose of contrast medium was 60% to 100% of the conventional dose given during standard angiography. With injections made close to the lesion and on the left side of the circulation, the mean dose of contrast medium was 27.5% to 42% of the conventional dose. Radiation exposure for each technique was markedly reduced in all age groups. A total of 92 digital subtraction angiograms were performed. Five studies were suboptimal because too little contrast medium was injected; in the remaining 87 injections, DSA and conventional studies resulted in identical diagnoses in 81 instances (p < .001 vs chance). The remaining six injections made during DSA failed to confirm diagnoses made angiographically by standard cutfilm angiography or cineangiography. We conclude that DSA usually provides diagnostic information equivalent to that available from cutfilm angiography and cineangiography, but DSA requires considerably lower doses of contrast medium and less radiation exposure than standard conventional methods.


Digital subtraction angiography (DSA) has recently been shown to be a valuable tool in the evaluation of great-vessel anomalies and of heart disease in the adult patient. Not only does the technique permit high-resolution imaging when injections of contrast medium are made at sites distant from the heart or lesion, but such imaging can also be achieved with low loads of contrast medium and reduced radiation exposure. These factors offer potential advantages in the diagnosis of congenital cardiac lesions in infants, children, and adolescents, and especially in those patients with complex, cyanotic heart anomalies in whom use of moderate-to-high doses of contrast medium during diagnostic cardiac catheterization may constitute a particularly high risk. Few studies that use DSA have been undertaken in the pediatric age group, and the diagnostic accuracy of this technique is still unclear. At the New York Hospital–Cornell Medical Center, we have evaluated DSA with a single-mask mode in 42 pediatric patients with congenital cardiac lesions.

Methods

Computer-based DSA was performed in 42 pediatric patients with congenital cardiac disease who were undergoing conventional cardiac catheterization and angiographic evaluation. The study group consisted of 18 male and 24 female patients (ages 2 months to 18 years, mean 7.8), and 12 of these patients were under 3 years old (table 1). The weight distribution was 3.4 to 78.5 kg, with a mean weight of 28.2 kg; 16 patients weighed...
TABLE 1
Patient population (n = 42)

<table>
<thead>
<tr>
<th>Age distribution (yr)</th>
<th>0-3</th>
<th>3-6</th>
<th>6-9</th>
<th>9-12</th>
<th>12-15</th>
<th>15-18</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
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<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>6</td>
<td>18</td>
</tr>
<tr>
<td>Females</td>
<td>5</td>
<td>8</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>24</td>
</tr>
<tr>
<td>Mean 7.8 yr</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>42</td>
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</table>

Weight distribution (kg)

<table>
<thead>
<tr>
<th>0-15</th>
<th>15-30</th>
<th>30-45</th>
<th>45-60</th>
<th>60-75</th>
<th>75-90</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Males</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>18</td>
</tr>
<tr>
<td>Females</td>
<td>9</td>
<td>8</td>
<td>4</td>
<td>---</td>
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<td>24</td>
</tr>
<tr>
<td>Mean 28.2 kg</td>
<td></td>
<td></td>
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<td>42</td>
</tr>
</tbody>
</table>

under 15 kg (table 1). The body surface area ranged from 0.2 to 1.97 m² (mean 0.94). None of the patients had congestive cardiac failure at the time of study.

As determined by standard film-based angiography and/or subsequent assessment at cardiac surgery, a total of 29 anomalies or combinations of lesions was present in our patients (table 2). Included were valvular lesions, intracardiac and extracardiac shunt lesions, and a group of miscellaneous conditions.

Routine right and left heart catheterization was performed with patients in the nonabsorptive state after sedation with 2 mg/kg meperidine (Demerol), 1 mg/kg promethazine HCl (Phenergan), and 1 mg/kg chlorpromazine (Thorazine).1.14 Venous and arterial catheters were inserted percutaneously into the right femoral vessels. For femoral vein punctures, No. 6F to 8F Berman balloon angiocatheters were used, and No. 6F to 7F UMI pigtail catheters were used for the arterial approach. When standard cutfilm angiography or cineangiography were performed, patients received a maximum of 1.0 to 1.25 ml/kg body weight at each injection of meglumine diatrizoate (Renografin 76). No patient received more than 3.0 ml/kg of contrast medium during the standard angiographic study. The maximum dose of contrast medium did not exceed 50 ml for any single injection. Contrast medium was delivered at a rate of 16 to 32 ml/sec, depending on catheter size and length.

At completion of the routine diagnostic catheterization and angiographic procedure, and only after the definite diagnosis had been established from the processed films and hemodynamic data, digital angiograms were obtained. For DSA, patients were positioned in the orientation that best defined the lesion during standard angiographic assessments. Informed consent from each patient and approval of the Cornell University Medical College Committee on Human Rights in Research were obtained before each DSA study. An American Edwards Laboratory CARDIAC 1,000 Digital Subtraction Angiography Computer was used. The computer was programmed to sample 30 frames/sec; for diagnostic accuracy and radiographic definition, these data were later compared in the same patient with data obtained by conventional biplane cutfilm angiography (2 to 6 frames/sec) or by cineangiography (60 frames/sec). For DSA, the amount of contrast medium injected depended on the site of injection. When injections were made at a site distant from the lesion, such as the venous side of the heart for lesions on the left side, the mean amount of contrast medium delivered varied between 60% and 100% of the conventional dose administered during standard angiography (figure 1). When injections were performed at central sites close to the lesion, or at the site of the lesion, the mean dose of contrast medium delivered ranged from 27.5% to 42% of the conventional dose (figure 1). For DSA, the rate of injection, which ranged between 16 and 32 ml/sec, was maximal for the catheter size and length. No patient received more than 1.0 to 1.5 ml/kg body weight of meglumine diatrizoate for digital angiography, and DSA added no more than 10 to 15 min to the total catheterization time. No patient received a total dose of contrast medium in excess of 4 ml/kg body weight during the entire procedure.

Radiation settings for infants and smaller children were 60 kVP for cutfilm angiography and 70 kVP for both cineangiography and DSA (figure 2). A total setting of 800 mA was used for biplane cutfilm angiography compared with settings of 100

FIGURE 1. Percent of conventional dose of contrast medium used during DSA. For injections made at a site distant from the lesion and on the right side of the circulation, the mean dose of contrast medium was between 60% and 100% of the conventional dose given during standard angiography. With injections made close to the lesion and on the left side of the circulation, the mean dose of contrast medium ranged from 27.5% to 42% of the conventional dose. ACG = angiogram; IVC = inferior vena cava; RA = right atrium; RV = right ventricle; PA = pulmonary artery; LA = left atrium; LV = left ventricle; AO = aorta.

TABLE 2
Lesions studied

<table>
<thead>
<tr>
<th>Regurgitant lesions</th>
<th>Obstructive lesions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aortic valve</td>
<td>Aortic stenosis</td>
</tr>
<tr>
<td>Mitral valve and prolapse</td>
<td>Subvalvular</td>
</tr>
<tr>
<td>Tricuspid valve</td>
<td>Coarctation of aorta</td>
</tr>
<tr>
<td>Ruptured sinus of vasa saliva</td>
<td>Pulmonic atresia</td>
</tr>
<tr>
<td></td>
<td>Pulmonic stenosis</td>
</tr>
<tr>
<td></td>
<td>— Valvular</td>
</tr>
<tr>
<td></td>
<td>Infundibular</td>
</tr>
<tr>
<td>Shunt lesions</td>
<td>Miscellaneous lesions</td>
</tr>
<tr>
<td>Atrial septal defect</td>
<td>Blalock-Taussig shunt</td>
</tr>
<tr>
<td>Coronary A-V fistula</td>
<td>Eccentric LVH</td>
</tr>
<tr>
<td>Patent ductus arteriosus</td>
<td>l-Transposition</td>
</tr>
<tr>
<td>Tetralogy of Fallot</td>
<td>Potts' anastomosis</td>
</tr>
<tr>
<td>Ventricular septal defect</td>
<td>Right ventricular outflow aneurysm</td>
</tr>
<tr>
<td></td>
<td>Septal aneurysm</td>
</tr>
</tbody>
</table>

A-V = atroventricular; LVH = left ventricular hypertrophy.
mA for cineangiography and 1.0 mA for DSA (figure 2). The exposure time for each biplane cutfilm angiogram was set at 6.3 msec and the pulse width for each cineangiogram frame was 1.0 msec. Equivalent settings for older patients were 80 kVp and 1200 mA for biplane cutfilm angiography, 70 kVp and 100 mA for cineangiography, and 70 kVp and 5 mA for DSA (figure 3). The exposure time for each cutfilm angiogram was set at 16.0 msec and that for each cineangiogram frame was 5.2 msec. Exposure measurements were performed with the mdh Model 1015C x-ray dosimetry system with the Model 10X5-6 6 cm³ ionization chamber. For each view or technique, the chamber was centered in the x-ray beam at the position of the entry surface in each patient. For cutfilm techniques, the tube potential (kVp), tube current (mA), and exposure time (msec) were set to the values used clinically. For fluoroscopy, cineangiography, and DSA techniques, which use the automatic brightness control system, we simulated the presence of patients by using aluminum attenuation of sufficient thickness to drive the x-ray generator to the tube potential, tube current, and pulse widths that had been recorded from the meters when the patients underwent dosimetry. Exposure times for fluoroscopy, cineangiography, or DSA were determined both by a measurement of beam-on time with a stopwatch while patients underwent dosimetry and by a review of videotapes at standard speed or by a count of the cineangiographic frames that had been exposed at 60 frames/sec. The total exposure time for biplane cutfilm angiography depended on the weight of the patient and varied from 6.3 msec per exposure in the smallest patient to 16.0 msec per exposure in the heaviest patient. Since 16 exposures were obtained in each plane, the total exposure times varied from 208 msec for infants to 512 msec for patients weighing more than 60 kg (exposure time × 16 msec × 2). For cineangiography, total exposure time varied similarly, depending on patient size and heart rate. With cineangiography performed at 60 frames per sec, the total number of exposed frames averaged 396 frames per cineangiogram in infants and resulted in a total exposure time of 396 msec. Similar values for older patients were an average of 600 frames per cineangiogram for 3.12 sec total exposure time.

To minimize diaphragm movement and obscuring of the heart, older patients who were able to cooperate were instructed to inspire fully and to maintain full inspiration during initial fluoroscopy in preparation of the mask (see below) for DSA, again just before injection of contrast medium, and until completion of the fluoroscopic sequence. This procedure usually took no more than 10 sec. However, smaller children and infants breathed at their normal rates throughout the fluoroscopic procedure. After the study was completed, images recorded by cutfilm angiography, cineangiography, and DSA were reviewed by three independent observers in blinded fashion to determine the extent to which diagnoses made from DSA reproduced those made from cutfilm angiographic, cineangiographic, and hemodynamic data. The observers also provided independent assessment of the quality of the angiograms obtained.

To obtain the DSA, the area of interest was imaged by fluoroscopy to produce a picture on the image intensifier (figure 4). This picture was converted into an analog electric signal by the television camera. The analog output from the television camera was then converted by the computer into a digital format at a rate of 30 frames/sec, by division of the image into a 512 × 512 pixel (picture element) matrix. The x-ray photon density, or brightness, of each pixel was quantified and the quantity thus determined was proportional to the number of photons incident on the image intensifier. The photon density of each pixel was recorded and stored digitally in the microprocessor memory. An initial set of 16 frames was averaged and stored in the memory to define the background radiation transmitted through the patient before injection of contrast medium. This background radiation was termed the "mask." After determination of the mask, the contrast medium bolus
was administered and fluoroscopy was repeated; the resulting images were digitized as before at a rate of 30 frames/sec. The single mask was then electronically subtracted from all subsequent images by the computer on a pixel-by-pixel basis, which resulted in subtraction or marked attenuation of all structures in the chest and in the relative enhancement of the image of the contrast medium within the field of view. This processed digital image was then converted back to an analog signal for viewing on a standard television monitor.

Chi-square analyses were used to compare the frequency of correct diagnoses vs chance.

Results

Diagnostic accuracy. We obtained 92 digital subtraction angiograms in 42 subjects. Early in our experience, five studies in children (ages 2 months to 2½ years) could not be interpreted because too little contrast medium (less than 20% of the conventional dose or less than 3 ml per injection) had been injected, which resulted in suboptimal opacification (figure 5). In the remaining 87 injections, digital and conventional studies resulted in identical diagnoses in 81 instances (p < .001 vs chance). In 16 of these, both conventional cutfilm angiograms or cineangiograms and digital subtraction angiograms were read as normal when injections were performed to rule out associated lesions in patients with other congenital cardiac defects. There were 50 injections in which conventional and DSA studies each indicated the presence of a single lesion, nine injections in which two lesions were identified, and three instances in which three lesions were identified by both methods. In three additional injections, both conventional cutfilm angiograms and digital subtraction angiograms were falsely read as normal when hemodynamic studies indicated the presence of a lesion. Two of these injections were performed in a 2-month-old infant weighing 3.5 kg who had pulmonary vein stenosis. One injection was made into the right ventricle and the second into the pulmonary artery in an unsuccessful attempt to define the site of pulmonary venous obstruction. In the remaining false-negative injection, both cutfilm angiograms and digital subtraction angiograms were read as normal in a 6½ year old patient who had an insignificant small atrial septal defect; in this patient, no oxygen step-up was found at atrial level, but diagnosis was made by catheter passage and by hydrogen gas–dilution studies that were positive in the right atrium and negative in the venae cavae.

In the remaining six of the 87 satisfactory injections

<table>
<thead>
<tr>
<th>CONVENTIONAL ANGIOGRAPHY</th>
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<tbody>
<tr>
<td>Normal</td>
</tr>
<tr>
<td>Normal</td>
</tr>
<tr>
<td>1 Lesion</td>
</tr>
<tr>
<td>2 Lesions</td>
</tr>
<tr>
<td>3 Lesions</td>
</tr>
<tr>
<td>No Lesions</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Unreadable (Too little contrast)</td>
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</table>

FIGURE 4. To obtain digital subtraction angiograms, the area of interest was imaged fluoroscopically before angiography, which produced a picture on the image intensifier (II). The picture was converted to an analog electric signal (A) by the television camera (TV). The analog signal was then digitized (D) by the computer at 30 frames/sec and the initial 16 frames averaged and stored in the microprocessor memory as the "mask." Fluoroscopy was then repeated after administration of contrast medium and the resulting images were digitized as before. The mask was then electronically subtracted from the new image and the resultant image was converted back to an analog signal for viewing on a standard television monitor.

FIGURE 5. Comparison of results of conventional angiography and digital angiography in 92 patients. Identical diagnoses were made with each technique in 81 instances. In six patients, DSA failed to confirm diagnoses made angiographically by standard techniques. Five patients had suboptimal injections of contrast medium. See text. AS = aortic stenosis; PS = pulmonary stenosis; ASD = atrial septal defect; Ecc. LVH = eccentric left ventricular hypertrophy; Pul. V. St. = pulmonary valve stenosis; VSD = ventricular septal defect; PDA = patent ductus arteriosus.

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(figure 5), DSA failed to confirm diagnoses made angiographically by standard cutfilm angiography or cineangiography. These patients ranged in age from 2 to 17\(\frac{1}{2}\) years. Five of the false-negative digital studies were in patients with a single lesion: mild aortic valvular stenosis in one child 16 years old, mild pulmonic valvular stenosis in two children, 2 and 3 years old, and atrial septal defect in two patients 11 years and 17 years old. In the two patients with atrial septal defect, failure to identify the defect resulted when digital angiograms were obtained from the inferior vena cava with the patient positioned in the left anterior oblique projection. During the levophase of those injections, no visualization of contrast medium was achieved in the right atrium after left atrial opacification. The diagnosis in one additional patient with two lesions (mild aortic stenosis and eccentric hypertrophy of the left ventricle) was not confirmed by the digital technique.

**Doses of contrast medium.** When lesions were assessed by intravenous administration of contrast medium, larger amounts were used than when contrast medium was administered directly into the left heart or into an area close to the site of the lesion. However, irrespective of the site of contrast medium administration (in all cases but one), doses for DSA were equal to or less than those used to image the same lesion with cutfilm angiography or cineangiography. Doses of contrast medium for DSA varied from 30% to 100% (average 79%) of the conventional dose in the 22 cases where injections for DSA were made into the inferior vena cava (doses of contrast medium for DSA, 10 to 45 ml, mean 21.6 ml, figure 1). Doses of contrast medium for DSA in the five right ventricular injections ranged from 25% to 140% (average 60%, doses of contrast medium for DSA, 5 to 16 ml, mean 7.4 ml) of that used for conventional angiography in the same patients; in six pulmonary artery injections, dosage was from 40% to 140% (average 76%, doses of contrast medium for DSA, 5 to 45 ml, mean 21 ml). In the 2-month-old patient weighing 3.5 kg with pulmonary vein stenosis, two digital angiograms were obtained, one in the right ventricle and the second in the pulmonary artery, with 140% (5.0 ml) of the conventional dose of contrast medium, but the site of the pulmonary venous obstruction was not defined. When this patient is excluded, the mean amount of contrast medium injected into the right ventricle and pulmonary artery was 40.5% (range 25% to 64%, 5 to 16 ml, mean 8 ml) and 63.6% (range 40% to 90%, 8 to 45 ml, mean 24.5 ml), respectively, of the dose administered for conventional angiography. Doses of contrast medium for DSA of left ventricular injections were 20% to 100% (average 41%, 3 to 35 ml, mean 9.4 ml) of conventional dosage, and comparisons to other sites of injection yielded similar values (figure 1). The absolute amount of contrast medium used in these studies ranged between 3 and 45 ml.

**Image quality.** When three observers subjectively compared the quality of radiographic definition among the three methods of angiography, definition by DSA was invariably deemed adequate for diagnostic purposes if no less than 3.0 ml of contrast medium was delivered per injection at central sites close to or at the lesion and if no less than 60% of the conventional dose was injected from distant sites.

**Radiation exposure.** The measured radiation exposure rates at entry surface in each patient revealed that to obtain diagnostic images, DSA involved markedly less radiation exposure than cutfilm angiography or cineangiography; these were approximately 10% of the exposure rate required for cutfilm angiography and about 4% of that required for cineangiography. Detailed exposure comparisons for individual patients depended on the total number of cutfilm angiographic films exposed and on the total time of the cineangiography and DSA runs. For example, in the smallest infant, weighing 3.4 kg, the radiation exposure with DSA was 140 millirads, while comparable radiation exposure for cutfilm angiography and cineangiography was 1120 and 6000 millirads, respectively (figure 2). For the oldest and heaviest patient weighing 78.5 kg, exposures were 700 millirads for DSA, 14,944 millirads for cutfilm angiography, and 15,600 millirads for cineangiography (figure 3).

**Discussion**

DSA in adult patients with great-vessel or cardiac diseases\(^1-12\) has been shown to be highly accurate in reproducing information available with more conventional methods. Few studies, however, have been performed in pediatric patients with congenital heart disease in whom the particular advantages of DSA, which include reduced doses of contrast medium and reduced radiation exposure, might be most important. Although the role of DSA in the pediatric patient with congenital heart disease is not yet established, encouraging reports have appeared. Weinstein et al.\(^2\) obtained digitally subtracted radiographic images at 6 frames/sec on a 256 x 256 x 8 bit matrix and were able to adequately identify cardiac chambers and to note the recirculation of contrast medium through septal defects in four patients. In addition, these investigators identified complicated congenital cardiac lesions, which included single-ventricle, double-chambered
heart and anomalous pulmonary venous return; these investigators estimated the ejection fraction, relative shunt flow, and cardiac output with densitometric analysis. Yiannikas et al.\textsuperscript{12} also used densitometry to quantitate shunt size. In a preliminary report of their experience with 100 patients with congenital heart disease (40 with left-to-right shunts), injections of contrast medium for DSA were made from a peripheral arm vein. They concluded that DSA compared favorably with cardiac catheterization in localizing intracardiac defects and in estimating pulmonary-to-systemic flow ratio, as well as right and left ventricular ejection fractions. In addition, they were able to identify associated lesions with a high degree of accuracy; in 85% of the patients, the diagnosis by DSA was in accord with the final diagnosis obtained by conventional methods.

Our data confirm these preliminary findings, which indicate that DSA can be applied successfully in the diagnosis of congenital heart disease in pediatric patients spanning a wide range of ages and weights. However, our method of contrast medium injection for DSA differed from that of previous studies in that injections were made in the inferior vena cava, or close to or at the site of the lesion, rather than in peripheral veins. With injections made centrally, we were able to reduce greatly the dose of contrast medium, as compared with earlier studies, without apparent loss of diagnostic accuracy. Furthermore, we were able to image the area of interest at 30 frames/sec with a 512 \times 512 pixel matrix, which potentially permits both accurate assessment of cardiac chamber function and sophisticated computer-based image processing. Although we made no attempt to quantitate flows or to define right or left ventricular function in this study, we and others have shown previously that in adults, left ventricular volumes and regional and global systolic function as determined by intravenous DSA are closely correlated with results obtained by conventional intraventricular cineangiography.\textsuperscript{15, 16}

The reduction in doses of contrast medium afforded by DSA is a major advantage in the pediatric patient. The dose-related toxic and potentially lethal effects of contrast medium in the pediatric age group are well documented, especially in those newborn infants with cyanotic lesions or cardiac failure during the first few hours or days of life.\textsuperscript{17-21} The usual dose of contrast medium necessary for images of diagnostic quality with cutfilm angiography and cineangiography is 1.0 to 1.5 ml/kg body weight.\textsuperscript{13, 14} Loading of contrast medium with these doses has been associated with rapid fall in pH with acidosis,\textsuperscript{17-19} which potentially can result in cardiac arrhythmias and deterioration in ventricular function. The fall in pH tends to be cumulative if a recovery period of 10 to 15 min between injections is not permitted, and it may be particularly marked in severely cyanotic newborn infants who often exhibit metabolic acidosis as a presenting feature of their illness.

A rapid rise in osmolality also results from contrast medium administration and may be significantly mitigated by the lower doses of contrast medium necessary with DSA. Increased blood osmolality may result in a sudden increase in intravascular volume with worsening of cardiac failure or pulmonary edema.\textsuperscript{20-22} It has been estimated that every 1.0 ml of hyperosmolar contrast medium results in a short term plasma expansion of 8 to 10 ml.\textsuperscript{18, 20} Thus, infants and children with incipient or overt cardiac failure may be placed suddenly at increased risk immediately after angiography. The present study indicates that adequate visualization of cardiac anomalies in pediatric patients may be attained with DSA after injections as small as 20% of conventional doses of contrast medium are made at or close to the site of the lesion, and injections as small as 60% of the conventional dose when made distant from the lesion or in the venae cavae; this reduces the risk of complications. Furthermore, when lesions are complex and added injections are required for diagnosis, multiple angiograms may be performed with DSA without exceeding acceptably safe limits of contrast medium doses.

Although DSA almost uniformly permits reduction in conventional doses of contrast medium necessary for diagnostic imaging, a limitation exists in that, with current equipment, the smallest bolus of contrast medium must exceed 3.0 ml and must be no less than 20% of the conventional dose delivered under high pressure for DSA to provide images of diagnostic quality. In our first five patients, three with ventricular septal defect and two with patent ductus arteriosus, doses of contrast medium were too small to permit an accurate image assessment, and in each instance the amount of contrast medium injected was less than 3.0 ml (figure 5). The smallest amount of contrast medium injected to achieve excellent visualization of the lesion was in a child with a patent ductus arteriosus who received 3.0 ml or 36% of the conventional dose injected into the left ventricle, which revealed an intact ventricular septum and confirmed the patent ductus arteriosus (figure 6). Other examples are depicted in figures 7 through 11.

In six patients (figure 5), DSA failed to define a lesion that had been confirmed by either cutfilm angi-
FIGURE 6. Comparison of standard aortogram (left) showing a patent ductus arteriosus, with digital left ventriculogram (right) showing an intact ventricular septum and confirming the patent ductus arteriosus. The patient, age 1 1/4 years and weighing 8.2 kg, received 36% (3.0 ml) of the conventional contrast medium dose for the digital ventriculogram.

ography or cineangiography. In five of these patients a single lesion was present (one aortic valve stenosis, two pulmonic stenoses, and two atrial septal defects). The remaining patient had two definable lesions, mild aortic stenosis, and eccentric left ventricular hypertrophy. Mild stenotic lesions of the semilunar valves may be difficult to define by conventional angiography as well; diagnosis often depends on the catheter-measured pressure differential across the valve. In both patients with the small atrial septal defect, the diagnosis was missed when assessment was attempted during the levophase of injections made in the inferior vena cava. In each instance 60% to 70% of the conventional dose of contrast medium was used. Angiographic diagnosis of an atrial septal defect may require conventional doses of contrast medium during DSA when performed from the inferior vena cava.

In addition to the reduction in doses of the contrast medium, another advantage associated with DSA is the marked reduction of radiation exposure to the patient as well as to the angiographer. High doses of radiation during cardiac catheterization and angiography

FIGURE 7. Tetralogy of Fallot in a 1 1/2-year-old patient, weighing 12.4 kg. The digital left ventriculogram (right) was obtained with 3.0 ml or 25% of the conventional contrast medium dose used for the standard left ventriculogram (12.0 ml, left). Note the ventricular septal defect and the overriding aorta.
have been shown to be potentially deleterious.\textsuperscript{23-27} Because of their small size, infants and children receive an increased radiation exposure from internal scatter during conventional angiography, which results in higher doses of radiation to both the gonads and the thyroid gland.\textsuperscript{26} Since children can be expected to live longer after exposure than adults, the overall consequences of radiation exposure are greater than in adults. The significance of direct gonad exposure has long been recognized, but the radiation exposure during angiography is relatively small.\textsuperscript{27} The consequences of thyroid sensitivity have recently been appreciated, since radiation exposure has been linked to thyroid carcinoma. Previous studies\textsuperscript{28, 29} indicate an incidence of thyroid cancer of between 1.6 and 9.3 cases per million per year per rad. Martin et al.\textsuperscript{26} found that with conventional angiography, the average skin radiation exposure is 17.1 R and the average thyroid exposure is 23 R. From this information, they calculated that in pediatric patients with a normal life expectancy,
the risk of developing thyroid carcinoma as a consequence of conventional angiography is about 20 times greater than the national incidence (0.7 per thousand compared with 0.04 per thousand), although a latent period in excess of 40 years between irradiation and clinical presentation may be present. Other investigators have expressed similar findings.

Radiation exposure may produce injury to other organ systems as well. Adams et al., in evaluating blood samples taken before and after cardiac catheterization with cineangiography in 20 children, found chromosomal damage in all samples taken after the study. In a subsequent study, the dose effect was shown to be enhanced by the use of a contrast agent during angiography. In addition, radiosensitivity is proportional to cell reproduction rate, thus making the

FIGURE 10. Aortograms from the patient in figure 9, but later during the angiogram. Note the descending aorta and the well-defined collateral vessels in the digital angiogram (right) compared with the standard angiogram (left).

FIGURE 11. Digital aortogram in a 14-year-old patient weighing 49 kg, after surgery for aortic valvular stenosis. Note the domed aortic valve and negative jet. We injected 16 ml or 32% of the standard contrast medium dose (49 ml).
hematopoietic system and bone marrow highly radiosensitive. While there are no reports in the literature of an increased incidence of leukemia in patients who underwent cardiac catheterization and angiography in childhood, periodic checkups and continued vigilance would appear prudent in these patients, given the potential for prolonged latency between radiation exposure and resulting neoplasia.

Numerous authors have reported damage to thoracic organs after therapeutic radiation. These include cardiac inflammation,33-35 constrictive pericarditis,34 and myocardial fibrosis.35,36 Since many children may require multiple cardiac catheterizations to manage their disease, consideration should be given to the possible accumulation of radiation effects during conventional imaging techniques and to subclinical damage that may not become evident until years later.37,38

Digital angiograms are performed with image-intensification fluoroscopy. While the tube potential settings for DSA, cutfilm angiography, and cineangiography are similar, the tube current settings are much higher for cutfilm angiography or cineangiography, varying from 100- to 250-fold greater than that for DSA; as a result, the actual measured radiation exposures were far less with DSA than with the two conventional angiographic methods (figures 2 and 3) and varied from approximately 4% to 10% of the conventional exposure. Thus, DSA provides greatly reduced radiation exposure without loss of required image resolution, thereby reducing possible hazards from radiation during catheterization.

While the pixel-by-pixel background subtraction method of DSA requires that patient movement be minimized to avoid misregistration of pixels and loss of resolution, our results indicate that this may be achieved by adequate sedation in preparation of the pediatric patient for cardiac catheterization; in adults and older children, diaphragmatic movement is reduced by breath-holding during the preparation of the mask and the subsequent angiographic sequence of the area of interest.

In summary, our data indicate that DSA, when performed with an injection either at a distant site such as the inferior vena cava, or centrally, close to the lesion, usually provides diagnostic information equivalent to that available from cutfilm angiography and cineangiography, while considerably less contrast medium and radiation exposure are required than in the conventional methods. Thus, DSA may be used as a screening test for patients with complicated lesions or in sick patients with contraindications for conventional angiography; as experience with DSA accrues, it may permit increasingly more accurate diagnostic imaging in the pediatric patient.

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References

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Digital angiography in the pediatric patient with congenital heart disease: comparison with standard methods.
A R Levin, H L Goldberg, J S Borer, L N Rothenberg, F A Nolan, M A Engle, B Cohen, N T Skelly and J Carter

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