Assessing Cardiac Anatomy With Digital Subtraction Angiography

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The use of intravenous digital subtraction angiography in the assessment of patients with congenital heart disease is described. Intravenous digital subtraction angiographic techniques are particularly helpful in visually assessing left to right shunts in patients with atrial and ventricular septal defects and anomalies of pulmonary venous return. Digital subtraction angiographic techniques have also been used to quantitate the magnitude of left to right shunts and have been compared with radionuclide-determined pulmonary flow/systemic flow ratios ($r = 0.89, p < 0.0001$). Digital subtraction angiographic techniques are particularly helpful in evaluating the right atrium, right ventricle and pulmonary arteries as well as the aorta and aortic arch. We have used digital subtraction angiographic techniques in the immediate and long-term postoperative evaluations of patients after congenital heart surgery. The safety of digital subtraction angiography lends itself to pediatric patients and can be performed on an outpatient basis. Digital subtraction angiography provides significant anatomic information that has modified our traditional approach to patients with congenital heart disease.

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Methods

Digital and analog systems with single or average multiple masks were utilized with two commercially available systems using pulsed (radiographic) or continuous fluoroscopic X-ray modes. The dose of contrast material was 0.5 to 1 ml/kg of Renografin-76 injected intravenously at rates of 5 to 30 ml/s. Younger patients were sedated with meperidine, promethazine and chlorpromazine. Initial framing rates were 1 to 6 frames/s using a 256 x 256 matrix. However, later studies were acquired at a framing rate of 30/s.

Results

Evaluation of pediatric patients with a left to right shunt. Atrial septal defect. Digital subtraction angiography has been particularly helpful in visually assessing left to right shunting in patients with an atrial septal defect. My group has studied 32 patients with an atrial septal defect and has visualized the shunt at the atrial level in all patients. The dilated right atrium, right ventricle and right ventricular outflow tract are clearly visualized (Fig. 1A). In the levo-phase study, one can clearly see recirculation at the atrial level (Fig. 1B). By placing cursors over various regions of the heart or the pulmonary artery, flow curves can be developed representing appearance and clearance of contrast medium (Fig. 2). Gamma variate fit analysis can then be applied to these curves for quantitation of the degree of left to right shunt. The techniques of digital subtraction angiography can also be utilized to assess the adequacy of repair, postoperatively demonstrating the intact atrial septum with normal pulmonary venous drainage (Fig. 3).

Ventricular septal defect. Digital subtraction angiography has also been helpful in identifying patients with a ventricular septal defect, although these defects have been somewhat more difficult to visualize than atrial septal defects. In some 400 studies, digital subtraction angiography has failed to detect three small ventricular septal defects that were also missed with oximetry, although they were...
Digital subtraction angiography has allowed subtraction of the upper portion of the right atrium through a large shunt at the atrial level. Digital subtraction angiography techniques have allowed subtraction of the upper portion of the right atrium, which appears blackened in this picture, with the white dye appearing in the right atrium secondary to the left to right shunt at atrial level. (Reprinted from Yiannikas J, et al. [5] with permission.)

Congenital defects of systemic and pulmonary venous return. Digital subtraction angiography has also been valuable in the evaluation of these congenital abnormalities. My group has 10 male and 6 female patients whose ages ranged from 1 day to 41 years (mean 13 years). Four patients with total anomalous pulmonary venous return to the superior vena cava or the coronary sinus had pre- and postoperative digital subtraction angiographic studies (Fig. 5A and B) and two newborn infants had such studies after repair of total anomalous pulmonary venous return below the dia-
phragm. Digital subtraction angiographic studies demonstrated a persistent left superior vena cava in nine patients in association with secundum atrial septal defect, partial anomalous pulmonary venous return, mitral valve replacement, subvalvular pulmonary stenosis, obstructed right superior vena cava, hypoplastic left heart syndrome and ventricular septal defect. Digital subtraction angiographic studies also demonstrated a vitelline vein remnant and azygos and hemiazygos venous connections in three additional patients.

Quantification of shunts. We studied 34 patients documented to have a left to right shunt at cardiac catheterization for quantitation of the degree of shunt. There were 20 patients with an atrial septal defect, 2 with partial anomalous pulmonary venous return, 1 with total anomalous pulmonary venous return, 9 with a ventricular septal defect, 1 with a patent ductus arteriosus and 1 with an atrioventricular canal defect. All patients had calculation of pulmonary to systemic flow (Qp/Qs) ratios by nuclear medicine techniques and the digital subtraction angiographic studies. Five patients from the nuclear studies and four from the digital subtraction angiographic studies were excluded from calculation of the Qp/Qs ratio because of fragmented and very prolonged boluses as judged by the input curves generated over the superior vena cava. In the remaining 25 patients, a significant correlation (r = 0.89) was found when comparing radionuclide and digital subtraction angiographic Qp/Qs ratio (p < 0.0001). In all of the 10 patients studied postoperatively, the Qp/Qs ratio calculated was less than 1.2:1 for both radionuclide and digital subtraction angiographic studies.

Evaluation of the right atrium, right ventricle and pulmonary arteries. Digital subtraction angiographic studies have been particularly valuable in pre- and postoperative
evaluation of children with abnormalities of the right atrium and tricuspid valve, particularly Ebstein’s anomaly. The atrialized portion of the right ventricle, the size of the right atrium and right ventricular function can be evaluated preoperatively in young patients with Ebstein’s anomaly. After valve replacement, digital subtraction angiographic techniques allow evaluation of the adequacy of valve replacement with anatomic definition of the size of the new right atrium, right ventricle and right ventricular outflow tract.

Digital subtraction angiography has also been helpful in the pre- and postoperative evaluation in patients with tetralogy of Fallot. We studied 10 male and 3 female patients ranging in age from 18 months to 54 years (mean 19 years). Digital subtraction angiography preoperatively demonstrated the position of the ventricular septal defect, overriding aorta, previous systemic pulmonary artery shunts and abnormalities of the right ventricular outflow tract and pulmonary arteries in four patients. Postoperatively, it identified the adequacy of right ventricular outflow tract reconstruction and ventricular septal defect closure in all 13 patients. A residual small ventricular septal defect (one patient), outflow patch aneurysms (two patients) (Fig. 6), proximal right pulmonary artery stenosis (one patient) (Fig. 6) and hypoplastic and distorted left pulmonary artery secondary to previous shunt (two patients) were all readily identified.

Digital subtraction angiographic techniques have also been helpful in evaluating the distal pulmonary arteries in pediatric patients with Al A. Gille’s syndrome, pulmonary emboli.

**Figure 5.** A, Intravenous digital subtraction angiogram in a 17 year old patient with total anomalous pulmonary venous return above the diaphragm. The **straight black arrow** points to the left atrium. The **curved arrow** points to a horizontal vein draining to a very large vertical vein with subsequent drainage to a dilated superior vena cava. B, Intravenous digital subtraction angiogram after repair of the total anomalous pulmonary venous return above the diaphragm, now demonstrating pulmonary venous return to the left atrium. (Reprinted from Yiannikas J, et al. [5] with permission.)

**Figure 6.** Intravenous digital subtraction angiogram 3 years after total repair in a 6 year old patient with tetralogy of Fallot, demonstrating a pericardial outflow tract patch aneurysm. The **curved arrow** points to mild stenosis of the proximal right pulmonary artery. (Reprinted from Moodie DS, et al. [1] with permission.)
and the distorted distal pulmonary artery anatomy that occurs pre- and postoperatively in patients with tetralogy of Fallot.

**Evaluation of the aorta and aortic arch.** We studied 25 patients using digital subtraction angiographic techniques with coarctation of the aorta. Digital subtraction angiography clearly has the unique ability to study pediatric patients with coarctation both pre- and postoperatively from a peripheral intravenous approach (Fig. 7A and B). In some patients with coarctation who require graft placement, digital subtraction angiographic techniques have been extremely helpful in defining the adequacy of the graft reconstruction of the aorta (Fig. 8). In addition to coarctation, abnormalities of the aortic arch and aortic dissection have been defined by digital subtraction angiographic techniques. We have found digital subtraction angiographic techniques to be the best method to follow the progression of aortic dilation in patients with Marfan’s syndrome (Fig. 9), in that digital subtraction angiographic techniques enable one to visualize the entire aorta and aortic arch, not just the proximal ascending aorta.

**Evaluation in infants with hypoplastic right and left heart syndromes.** We used digital subtraction angiographic techniques in the postoperative evaluation of four infants having surgery for hypoplastic right and left heart syndromes. All infants had 3 cc or less of Renografin-76 injected intravenously for the study. Two infants with hypoplastic right heart syndrome demonstrated on the digital subtraction angiographic studies growth of the right ventricular chamber. One infant developed a pericardial outflow tract aneurysm. Two infants with hypoplastic left heart syndrome had postoperative studies at 15 and 20 days after surgery; intravenous digital subtraction angiography demonstrated the adequacy of systemic and pulmonary artery flow and normal right ventricular function.

**Miscellaneous conditions.** Digital subtraction angiographic techniques have also been utilized in evaluating pediatric patients with complex congenital cardiac defects. We evaluated patients with univentricular heart, corrected transposition of the great vessels, dextrocardia with situs inversus, and tricuspid atresia; the digital subtraction angiographic studies have provided good anatomic demonstration of the intracardiac abnormalities.

In addition, we studied patients with right- and left-sided intracardiac tumors; again digital subtraction angiography demonstrated good definition of the tumor. Digital subtraction angiographic techniques would seem to obviate the necessity for cardiac angiography in most of these patients.

We also evaluated two patients with aneurysms of the atrial septum and two with aneurysms of the ventricular septum with clear delineation pre- and postoperatively of the anatomic abnormalities and associated intracardiac defects.

Digital subtraction angiographic studies have provided excellent anatomic definition using intraarterial injection in patients with congenital coronary artery anomalies, partic-

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**Figure 7.** A. Preoperative intravenous digital subtraction angiogram in a 9 year old patient with coarctation of the aorta, demonstrating the coarctation in its usual position just distal to the left subclavian artery. The arrow points to a dilated internal mammary vessel. B. Postoperative intravenous digital subtraction angiogram after coarctation of the aorta repair. The large arrow points to the area of the previous coarctation. The small dark arrows point to a now normal-appearing internal mammary vessel. (Reprinted from Moodie DS. Digital subtraction angiography. JACC Vol. 5, No. 1 January 1985:485-545.)
Figure 8. Intravenous digital subtraction angiogram in a patient with long segment coarctation of the aorta who had two previously unsuccessful attempts at repair. The patient had a graft placed from the upper descending aorta to the lower descending aorta bypassing the long segment coarct. The digital subtraction angiography study clearly shows the long segment coarctation and the graft in good position with good distal aortic flow.

Figure 9. Preoperative intravenous digital subtraction angiogram in a 17 year old patient with Marfan’s syndrome, demonstrating a mild ascending aortic aneurysm. Arrows point to the dilated ascending aorta.

Figure 10. A, Intraarterial digital subtraction angiogram in a patient after Bland-White-Garland repair with ligation of the anomalous coronary artery from inside the pulmonary artery and mitral valve replacement. The digital subtraction angiographic study shows persistence of some prominent right coronary artery collaterals. B, Intravenous digital subtraction angiogram demonstrating persistent drainage of the circumflex vessel into the main pulmonary artery. (Reprinted from Moodie DS, et al. [1] with permission.)
ularly those with anomalous origin of the left coronary artery from the pulmonary artery (Fig. 10A and B)

**Future Development**

The ability to inject contrast material through a peripheral arm vein in patients at rest and during exercise has allowed us to evaluate right and left ventricular function during stress with digital subtraction angiographic techniques in patients with congenital heart disease. Digital subtraction angiographic techniques provide a resolution 10 times greater than that of nuclear medicine and allows adequate assessment of wall motion and ventricular function. This is obviously helpful in evaluating pre- and postoperative patients with congenital cardiac defects and coronary artery disease.

**Discussion**

My colleagues and I have previously described the use of intravenous digital subtraction angiographic techniques in the evaluation of patients with congenital heart disease (1,2) and congenital abnormalities of the aorta and aortic arch (3), intracardiac masses (4), anomalies associated with intracardiac left to right shunts (5) and aneurysms of the atrial and ventricular septa (6). Only a modest amount of intravenously administered contrast material is necessary for digital subtraction angiographic studies. The safety of digital subtraction angiography lends itself ideally to pediatric patients with congenital heart disease and can be performed on an outpatient basis. There have been no significant complications associated with intravenous digital subtraction angiography to warrant medical care in our patients. We have had three instances of extravasation of contrast material during intravenous injection in some 450 studies. Radiation exposure during the usual digital subtraction angiographic study was only 2 to 3 rads. Digital subtraction angiography provides information and diagnostic clarity similar to that of conventional angiographic studies in 86 to 100% of the patients we studied. The frequency of diagnostic studies is dependent on the abnormalities being evaluated. Digital subtraction angiography provides significant anatomic information that has already modified our traditional approach in pediatric patients with congenital heart disease.

**References**