

Digital subtraction angiography in infants and children with congenital heart disease

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SUMMARY Digital subtraction angiography was used as the sole imaging technique in 95 infants and children aged 13 hours to 16 years undergoing cardiac catheterisation for the investigation of congenital heart disease. Injections of diluted contrast medium were made selectively at central sites, and the images were obtained using continuous image intensification fluoroscopy at either 32.25 nC/kg/s (125 μ R/s) or 129 nC/kg/s (500 μ R/s). In all cases images adequate for diagnosis and management were obtained with appreciably less contrast medium and a lower radiation dose than in a comparable group of patients using conventional biplane cineangiography. Thus digital subtraction angiography is a viable alternative to biplane cineangiography for children with congenital heart disease.

Digital subtraction angiography is now well established as a means of vascular imaging in the adult. Its use in paediatric practice has, however, been limited¹ in spite of the potential advantages of both lower radiation exposure and a lower dose of radiographic contrast medium compared with conventional cineangiography. Although there have been occasional reports of the use of digital subtraction angiography in the investigation of congenital heart disease,²⁻⁴ the techniques used have varied, and its precise role has yet to be established. Recently, we have had the opportunity to evaluate its performance as an alternative to conventional biplane cineangiography at the time of cardiac catheterisation, and we report our experience with the first 95 patients investigated in this way.

Patients and methods

EQUIPMENT

A commercially available digital subtraction angiographic unit was used (Siemens Angiotron). With this unit the video signal from the image intensifier television camera is stored unprocessed in analogue form on

magnetic tape. Simultaneously, the signal passes through a sequence of logarithmic amplification, analogue to digital conversion, and digital subtraction of images before and after the injection of contrast. The subtracted image is converted back into analogue form, and the angiogram is viewed instantaneously in real time on a television monitor. For convenience of replay and in order to review the angiogram in slow motion we recorded the subtracted images on a high quality reel-to-reel video tape recorder.

The stored unprocessed video information could be replayed through the subtraction sequence varying the grey scale window width to reduce or increase contrast or varying the type of subtraction used. Each angiogram was viewed initially in continuous imaging (fluoroscopic mask) mode.⁵ In this mode an integrated mask image of 16 video frames was stored before the injection of contrast medium. The integrated mask image serves to blur both the moving non-opacified cardiac outline and to a lesser extent the respiratory movement in patients too young to suspend respiration for the duration of the angiogram. The stored mask image was then subtracted from successive single frames after the injection of contrast medium, and after amplification the subtracted angiogram was viewed in real time at 25 frames/s. Each angiogram was also analysed in time interval difference mode,⁵ in which the subtraction is performed between successive frames after opacification with contrast rather than from a stored non-opacified mask. In principle, the subtracted images in this

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Table Diagnostic groups of patients investigated using digital angiography and biplane cineangiography. Figures are numbers of patients

	Angiography	
	Digital	Cine
Tetralogy of Fallot and pulmonary atresia	16	19
TGV with or without VSD or PS	13	13
VSD with or without PS	13	10
Coarctation or aortic arch interruption	10	12
Aortic valve lesion	6	7
Pulmonary valve lesion	8	2
Single ventricle	5	4
Total or partial anomalous pulmonary venous connexion	4	4
Atrioventricular defect	3	3
Miscellaneous	17	20
Total	95	94

TGV, transposition of great arteries; VSD, ventricular septal defect; PS, pulmonary stenosis.

mode would consist of frame 2 minus frame 1 followed by frame 3 minus frame 2 and so on in sequence. The gap between the two frames could be varied from zero to eight frames. The subtracted angiograms were obtained using continuous fluoroscopy with radiation dose rates of either 32.25 nC/kg/s (125 μ R/s) or 129 nC/kg/s (500 μ R/s).

STUDY POPULATION

Ninety five patients with congenital heart disease were studied using digital subtraction angiography as the only angiographic imaging technique. The patients were unselected and were representative of those currently examined by cardiac catheterisation in this hospital. Their ages varied from 13 hours to 16 years (median 11 months) and their weights from 1.7 kg to 54 kg (mean 11.4 kg). Seventeen were less than 3 months old, and 10 were studied within the first week of life. The diagnostic groups are shown in the Table.

ANGIOGRAPHY

Cardiac catheterisation was carried out according to our usual practice. Patients over 3 months of age were sedated with ketamine 3 mg/kg; those under 3 months of age were studied unsedated. One child with Down's syndrome had a general anaesthetic, and two neonates were supported on ventilators at the time of the procedure. Venous and if necessary arterial catheters were introduced percutaneously from the right femoral vessels, and after the collection of haemodynamic data selective single plane angiograms were obtained. To achieve optimal dispersion of contrast medium at the site of injection we used a bolus volume of contrast identical to that which our previous experience of conventional biplane cineangiography suggested was appropriate to the circumstances. Iopamidol (370 mg I/ml) was diluted to half standard

concentration (185 mg I/ml) in sterile water and injected using a power injector at flow rates varying from 3 to 40 ml/s. Bolus volumes varied from 0.4 to 2.0 ml/kg. In three patients with aortic arch lesions iopamidol (370 mg I/ml) was injected into the pulmonary artery to achieve adequate visualisation of the defect, and in one patient iopamidol (123 mg I/ml) was used for a selective pulmonary angiogram. Standard radiographic projections for congenital heart disease were used,⁶ the initial angiogram being taken in the projection considered most likely to provide diagnostic information. A second or third angiogram from the same site was obtained using a different projection when necessary. In only five patients was respiration suspended during the angiogram.

COMPARATIVE DATA

Early in our experience with digital subtraction angiography three patients, whose study had been concluded satisfactorily, each had one single plane conventional cineangiogram using iopamidol (370 mg I/ml) to verify the findings and to obtain images for direct comparison with the digital images. The total volume of contrast medium used in these patients did not exceed 4.0 ml/kg.

To assess the reduction in the dose of contrast medium made possible by digital subtraction, data were obtained on 94 consecutive patients who underwent cardiac catheterisation in this hospital using cineangiography in the period immediately before the present study. The median age of these patients was 8 months (range 1 day to 12 years) and their mean weight 10.8 kg (range 2.5 to 32 kg). The range of defects investigated was very similar to that of the group investigated using digital subtraction (Table).

Results

Two hundred and forty eight angiograms were performed in the 95 patients: 88 from the left ventricle, 59 from the right ventricle, 15 from the only ventricle present, 42 from the aorta, 27 from the pulmonary artery, nine from a central systemic vein, six from a pulmonary vein, and one each from the left and right atria. From 116 sites a single angiogram gave sufficient diagnostic information. In a further 45 sites two angiograms were performed, mainly to obtain information in a second plane, but two angiograms were repeated because of gross patient movement and two because of operator errors. Three angiograms were performed in 14 sites. The total volume of radiographic contrast medium (185 mg I/ml) in each study varied from 0.8 ml/kg to 8.0 ml/kg (mean 3.4 ml/kg). By comparison, in the previous 94 consecutive patients studied using conventional biplane cineangiography, the volume of contrast (iopamidol

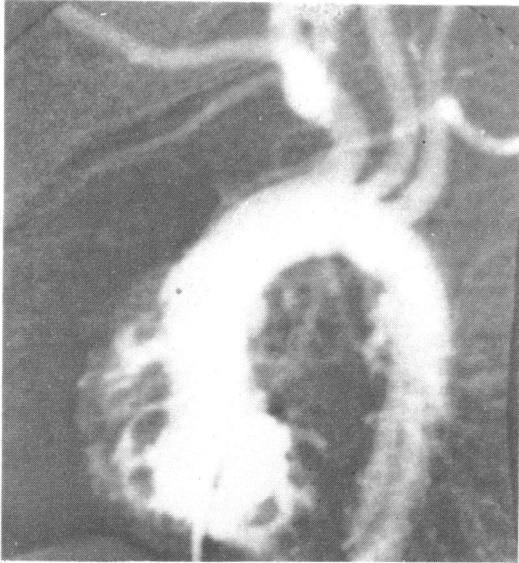


Fig. 1 Right ventricular angiogram in a patient aged 10 months (weight 7.7 kg) with transposition of the great arteries. 1.3 ml/kg of iopamidol 185 mg I/ml was used with a radiation exposure rate of 32.25 nC/kg/s (125 μ R/s).

370 mg I/ml) varied from 0.8 ml/kg to 7.4 ml/kg (mean 2.7 ml/kg). One hundred and twenty one angiograms were obtained at a radiation exposure of 32.25 nC/kg/s (125 μ R/s) and 127 were obtained at 129 nC/kg/s (500 μ R/s).

All the catheter studies were concluded satisfactorily using digital subtraction angiography alone, and it was not necessary to re-examine any patient using cineangiography. In three of the first 13 patients studied we obtained a single plane cineangiogram at the end of the study in order to compare the images obtained by digital subtraction with those on cine films. In two of these cases the information obtained by digital subtraction was identical to that on cine film, and in one case the subtracted angiogram was clearly superior.

Direct injection of approximately 1 ml/kg of contrast medium containing 185 mg I/ml into a ventricle which was not subject to volume overload produced a high quality angiogram with good contrast both within the ventricle and in the downstream arterial branches (Fig. 1). Such angiograms were produced at the lower of the two available fluoroscopic dose rates. In the presence of significant valve regurgitation or a large left to right shunt larger volumes of this medium (up to 2 ml/kg) were given, and the higher of the two fluoroscopic dose rates was used (Fig. 2). To examine the great vessels the lower fluoroscopic dose rate was

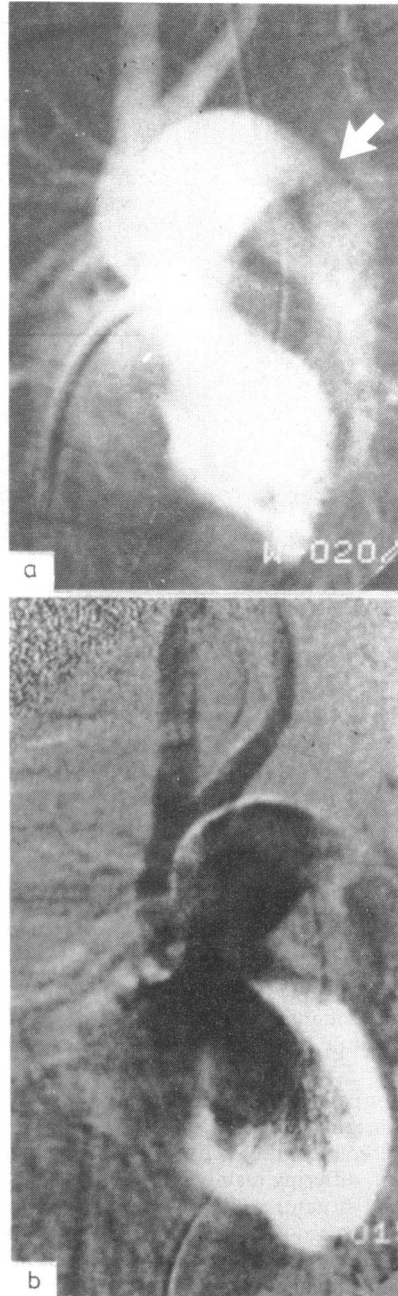


Fig. 2 Left ventricular angiogram in a patient aged 4 days (weight 2.8 kg). 1.8 ml/kg of iopamidol 185 mg I/ml was used with a radiation exposure rate of 129 nC/kg/s (500 μ R/s). (a) Continuous imaging mode shows a ventricular septal defect (not profiled in this view) and interruption of the aortic arch distal to the left common carotid artery. The descending aorta fills via a ductus arteriosus (arrowed), but the ascending aorta and main pulmonary artery are superimposed. (b) Time interval difference mode shows details of the ascending aorta and main pulmonary artery more clearly.

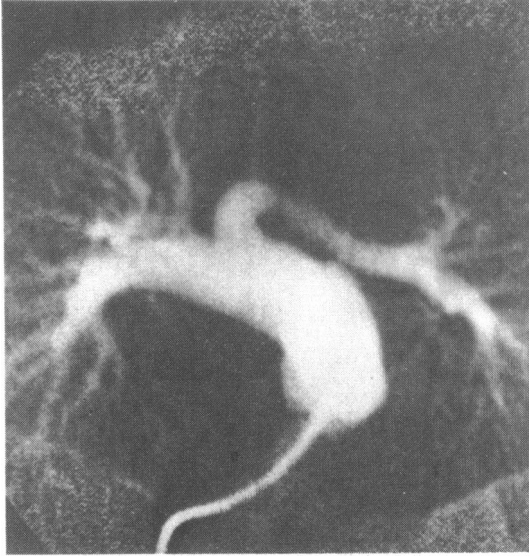


Fig. 3 Pulmonary angiogram in a child aged 18 months, (weight 11.5 kg) with a left pulmonary artery sling. 0.7 ml/kg of iopamidol 123 mg I/ml was used with a radiation exposure of 32.25 nC/kg/s (125 μ R/s).

used routinely in the absence of shunts or valve regurgitation, and volumes of contrast medium varied from 0.8 ml/kg to 1.2 ml/kg. Contrast medium containing only 123 mg I/ml gave adequate images of a pulmonary artery anomaly (Fig. 3). Excellent visualisation of lesions in the distal aortic arch was obtained in three patients by the injection of 1 ml/kg of iopamidol (370 mg I/ml) into the pulmonary artery (Fig. 4). Fourteen patients with isolated pulmonary or aortic valve lesions were studied. Abnormal valve leaflet motion was identified in all cases (Fig. 5), the minimum peak systolic pressure gradient being 35 mm Hg.

For most patients analysis of the angiogram in continuous imaging mode was sufficient. This mode closely resembles the conventional cineangiogram (Figs. 1-5), differing mainly in the relative absence of background structures. Because most of our patients were unable to co-operate in suspending respiration during the angiogram the ribs were evident in almost all of our angiograms, but this did not hinder interpretation of the dynamic images. When respiration was unusually deep or the patient was restless during the angiogram, however, analysis in time interval difference mode was helpful since this mode is relatively unaffected by movement. Analysis in time interval difference mode was also valuable in other circumstances. Details of the distal aortic arch were sometimes better appreciated by analysis in this way

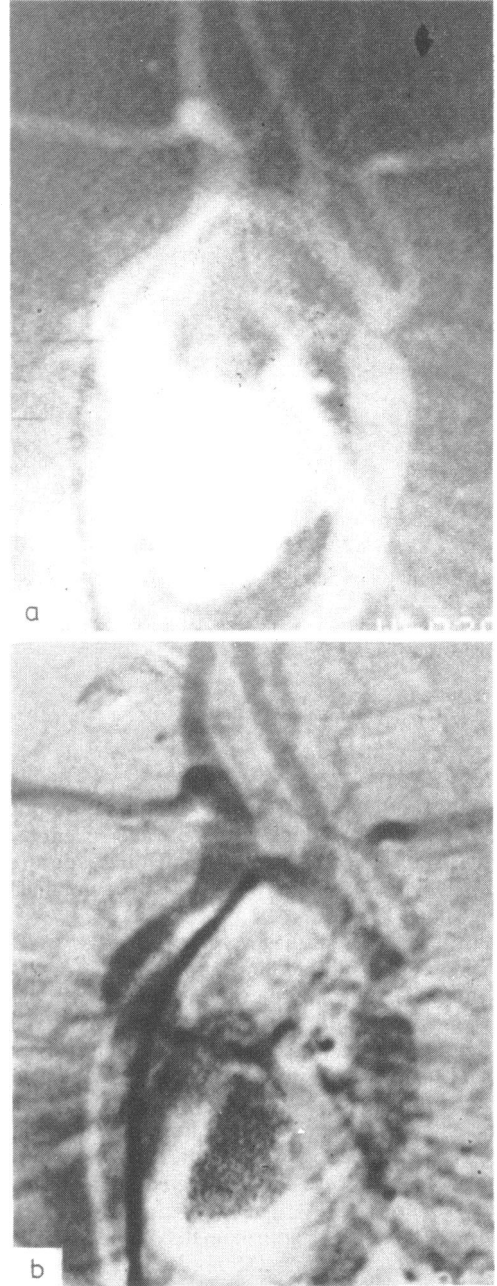


Fig. 4 Laevophase of pulmonary angiogram in a patient aged 3 weeks (weight 3.9 kg). 1.0 ml/kg of iopamidol 370 mg I/ml was used with a radiation exposure of 32.25 nC/kg/s (125 μ R/s). (a) Continuous imaging mode. (b) Time interval difference mode. The aortic coarctation is well seen in both modes but was best appreciated in time interval difference mode when viewing the dynamic images.



Fig. 5 Left ventricular angiogram in a patient aged 14 years (weight 37 kg) with valvar aortic stenosis (peak systolic gradient 50 mm Hg). 0.9 ml/kg of iopamidol 185 mg I/ml were used with a radiation exposure of 129 nC/kg/s (500 μ R/s).

(Fig. 4). Where both great arteries filled almost simultaneously from a ventricular angiogram and the great arteries were superimposed analysis in time interval difference mode allowed clearer visualisation of the anatomy (Fig. 2). Small left to right shunts were easily identified after right heart injections of contrast in both modes of processing.

Discussion

Digital subtraction angiography allows high quality vascular imaging using relatively small volumes of radiographic contrast medium. In spite of this, its application to the investigation of infants and children with congenital heart disease has received little attention. Buonocore and colleagues,⁴ using serial imaging (radiographic single mask) mode⁵ at 6 frames/s, studied 54 patients with congenital heart defects. Contrast was injected into a peripheral vein, and technically satisfactory images were obtained in 51 patients. Seven patients were thought to have normal

hearts, although three of the seven were subsequently shown to have ventricular septal defects on left ventricular cineangiography. In the remaining 44 patients, 90 anatomical defects were identified, and for 67 of these defects the information obtained by digital subtraction angiography was considered sufficient in retrospect to have made cardiac catheterisation unnecessary. Similar satisfactory results were obtained by the same group in the evaluation of congenital abnormalities of the aortic arch.² The mean age of the patients in these reports, however, was 20 years⁴ and 18 years.² Although occasionally infants under 3 months of age were included, it is clear that the selection of patients was totally different from that in a specialised paediatric unit, where a high proportion of patients investigated are under 2 years of age.

Although an increasing amount of information is now available to the paediatric cardiologist from cross sectional echocardiography, and in some circumstances cardiac catheterisation may not be needed as a preliminary to surgical treatment,⁷ at present many children with congenital heart disease undergo cardiac catheterisation to collect haemodynamic data and confirm the anatomical findings predicted by echocardiography. For this reason the experience of Levin *et al*³ is more relevant to current paediatric practice. These investigators studied 42 patients aged 2 months to 18 years at the time of cardiac catheterisation and compared the results of digital subtraction angiography with those of either biplane cut-film angiography at 6 frames/s or cineangiography at 60 frames/s. Their study showed both the diagnostic accuracy of angiography using digital subtraction and the reduction in the dose of contrast medium and in radiation exposure to the patient by this method. The mean age of the patients studied was 7.8 years, however, and no neonates were included in the study group.

For most paediatric cardiologists biplane cineangiography is the standard against which any alternative imaging system must be judged, and our intention was to assess whether digital subtraction angiography could provide a satisfactory alternative for all patients with congenital heart disease. We, therefore, used selective injections of contrast medium diluted to half standard concentration delivered as close as possible to the site of the lesion. A single plane angiogram was performed, assessed, and if necessary repeated in a second or third projection. Since the bolus volume given at each injection was identical to that which we would have used for cineangiography each angiogram was obtained with 50% of the contrast medium that we would normally have used. The overall saving in contrast medium dose is, therefore, entirely related to the fact that on many occasions only a single plane angiogram was considered necessary. This ability to

view one plane of angiography before proceeding with a second plane without exceeding safe concentrations of contrast medium seems to us to be a useful advantage. Comparison of our study group with 94 consecutive patients studied using biplane cineangiography shows that using the technique as described an overall reduction in the dose of contrast medium of about 40% is possible. In view of the potentially toxic effects of contrast medium,^{8,9} particularly in ill babies, this saving must be appreciable. In retrospect the degree of contrast achieved in some angiograms, particularly in chambers which were not subject to volume overloading, was such that images which would have been satisfactory for diagnostic purposes could have been obtained with even smaller volumes of contrast medium, and further savings are probably possible. Levin *et al* found that when injections were made close to the site of the lesion the dose of contrast medium needed ranged from 27.5 to 42% of the conventional dose.³

For technical reasons it was not possible to obtain cineangiograms simultaneously with digital subtraction angiograms. Although early in our experience three cineangiograms were performed to verify findings, they did not contribute additional information to the study, and in one case the digital angiogram was clearly superior. The quality of the images produced by digital subtraction angiography was such that we considered further angiography was unnecessary for patient management. Additional exposure to both radiation and further increments of contrast medium solely to provide comparative information could not in our opinion be justified. The images produced by the technique described were in most respects comparable, and sometimes superior, to those currently obtainable in our catheter laboratory using conventional techniques. Compared with the video image, cine film provides better line resolution and definition, but we did not feel that this loss of sharpness of the video image was clinically important. The video image offers better contrast, and the manipulation of the degree of contrast by the operator to provide the optimum image was a useful feature of the digital system which cannot be reproduced with cine film. In addition, the video images are immediately available for analysis with no delay due to film processing.

Radiation exposure during cardiac catheterisation for congenital heart disease is considerable,^{10,11} with about 20 to 25% of the total exposure occurring during the brief periods of cineangiography. Although long term follow up studies of patients who have had cardiac catheterisation in childhood have yet to be reported, measures which result in a reduction in exposure are clearly desirable, particularly since children appear to be more radiosensitive than adults.¹²

Our angiograms were obtained using image intensification fluoroscopy at either 32.25 nC/kg/s or 129 nC/kg/s (125 or 500 μ R/s) exposure rate with approximately half of the angiograms exposed at the lower of the two rates. We did not measure exposure during the angiography, but the reduction in exposure using digital subtraction angiography performed in this way has been well documented.³ Exposure during cineangiography is approximately 5.16 nC/kg/s (20 μ R) per cine frame, and that at the higher of our two dose rates is equivalent to that produced by cineangiography at 25 frames/s. In their discussion of ways in which exposure could be reduced during cardiac catheterisation, Waldman *et al* drew attention to the possibility of using slow cine frame rates for some angiograms without losing essential information and also to the use of single plane filming in some limited circumstances.¹¹ Digital subtraction angiography makes it possible for all angiography to be performed initially in a single plane without the risk of having to expose the patient to unacceptable amounts of contrast medium if the first angiogram does not provide complete information. In this study single plane filming provided adequate information in 116 out of 175 sites.

From our experience in using digital subtraction angiography in these 95 patients we conclude that it offers a viable alternative to biplane cineangiography in the investigation of congenital heart disease. There are two main advantages—namely, the reduction in radiation exposure brought about by the use of cineangiography and the reduction in contrast medium dosage made possible by enhancement of the opacified images. Moreover, selective central injections of diluted contrast medium produce angiograms of satisfactory quality. Others workers have shown that, at least in older children, peripheral injections of contrast may be all that is needed.⁴ Although these two factors are the major advantages of digital subtraction angiography, there are other benefits which might be mentioned. Videotape serves as a satisfactory archival format for the images produced by real time cross sectional echocardiography, and the use of the same format for angiographic material would undoubtedly be convenient for the user. Finally, the capital cost of a single plane angiographic installation with digital subtraction facility is appreciably less than that of a conventional biplane cine system, and, although we have not yet been able to make a complete assessment, the running costs of a system based on video tapes should also be lower than those for cine film.

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