RIGHT AND LEFT VENTRICULAR DIGITAL SUBTRACTION ANGIOCARDIOGRAPHY - GLOBAL AND REGIONAL ACCURACY.

ANGIOCARDIOGRAPHIE PAR SOUSTRACTION NUMERIQUE DU VENTRICULE DROIT ET GAUCHE: PRECISION GLOBALE ET LOCALE.

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RESUME

L'angiocardiographie est du valeur considérable pour analyser la dimension de la cavite du ventricule droit et gauche,mais les méthodes conventionelles nécessitent une quantité elevée du produit de contraste. Dans cet étude nous avons applique la soustraction numérique au projection biplane du ventricule droit et gauche, apres l'injection ventriculaire chez des enfants ayants une maladie cardiaque congénitale. Les paramètres du volumes et ces obtenues par l'angiocardiographie conventionelle ont été mis en relation. Il y avait une réduction (RV/LV) de la quantité du produit de contraste a 30%/35%, de la vitesse d'injection a 30%/55%, de la dose de rayon-x a 75%/77% et de l'éctopie ventriculaire a 50%/30% respectivement a l'angiocardiographie conventionelle. Il y avait une bonne corrélation pour EDV (r=0.995/0.988) et ESV (r=0.988/0.992) obtenue par les deux méthodes. La soustraction numerique permet la determination exacte des paramètres du volume du ventricule droit et gauche chez des enfants souffrants d'une maladie cardiaque congenitale.

SUMMARY

Angiocardiography is of considerable value in the dimensional analysis of the right and left ventricular cavity, but conventional methods necessitate large amounts of contrast medium. In this study the digital subtraction technique was applied to biplane right and left ventricular projections of children with congenital heart disease after ventricular injection of a small dose of contrast medium. Volume parameters were compared with those obtained from conventional angiocardiograms. Contrast medium was reduced (RV/LV) to 30%/35%, flow rate to 30%/55%, x-radiation to 75%/77%, and ventricular ectopy to 50%/30% of conventional angiocardiography. There was a good correlation for EDV (r=0.995/0.988) and ESV (r=0.988/0.992) obtained with both techniques. Digital subtraction angiocardiography allows accurate determination of volume parameters of the right and left ventricle in children with congenital heart disease.

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Introduction

Several imaging techniques are available for evaluation of ventricular performance. Because of its high spatial resolution and its capacity to permit visualization of all borders of the ventricular projections, x-ray transmission ventriculography after injection of radiopaque contrast medium directly into the ventricle is considered the standard method for such assessment. However, this technique requires a high x-ray dose and a large amount of contrast medium. In addition a ventricular injection is often associated with catheter induced ventricular ectopic rythm, precluding optimal assessment of ventricular function. To avoid these difficulties and to reduce x-ray radiation and amount of contrast medium we have employed image enhancement techniques in order to determine the extent to which digital subtraction right ventriculography after injection of small amounts of contrast medium with reduced flow into the ventricle can provide information previously available only with large intraventricular contrast administration.

Methods

Study patients. All patients studied were undergoing routine diagnostic cardiac catheterization for clinically indicated reasons.

RV-group (n=18): 3 infants under 1 year of age, 9 children between 1 and 6 years, and 6 between 6 and 18 years. Their age ranged from 18 days to 18 years (mean:7 years), their length from 50 to 193 cm (mean:114 cm), their weight from 3 to 71 kg (mean:25.4 kg), and their body surface area from 0.203 to 1.99qm (mean 0.873qm). Diagnoses included: pre and post operative tetralogy of Fallot (n=4), ventricular septal defect (n=3) pulmonary stenosis (n=3), aortic stenosis (n=2), patent ductus arteriosus (n=1), congestive cardiomyopathy (n=1), and combined lesions (n=6).

LV-group (n=18): 3 infants under 1 year of age, 3 children between 1 and 6 years, 14 between 6 and 18 years, and 5 older than 18 years. Their age ranged from 5 days to 60 years (mean:15 years), their length from 50 to 193 cm (mean:140 cm), their weight from 3 to 81 kg (mean:40 kg), and their BSA from 0.203 to 1.99 qm (mean 0.873qm). Diagnoses included: atrial septal defect (n=3), valvular aortic stenosis and insufficiency (n=9, mitral disease and pulmonary hypertension (n=2), ventricular septal defect (n=2), coarctation (n=3), postop tetralogy of Fallot (n=2), simple transposition of the great arteries (n=1) and no cardiac disease (n=3).

Cardiac catheterization was performed with local lidocaine anesthesia under sedation (infants under 6 months: no medication, infants between 6 and 12 months: 10 mg/kg acidum phenylbarbituricum; older children: pethidine 1-1.5 mg/kg, atropine 0.01-0.015 mg/kg, acidum phenyl- barbituricum 10 mg/kg).

Data acquisition. Conventional (CA) and digital subtraction angiocardiography (DSA) were performed with a 6F or 7F Berman catheter inserted into the femoral vein and artery, respectively, using a modified percutaneous Seldinger technique.

1.03 ml/kg body weight (0.63 to 1.55 ml/kg) of diatrizoate meglumine (Urografin, Schering AG Berlin) at 12.4 ml/s (4-25 ml/s) were injected into the right ventricle for angio and 0.29 ml/kg (0.17 to 0.38 ml/kg) at 6.9 ml/s (4 to 14 ml/s) for DSA and into the LV: .79 ml/kg diatrizoate (.45 to 1.22) at 15.4 ml/s (4-24) for angio and .28 ml/kg (.15 to.47) at 8.4 ml/s (4-18) for DSA. The injection was always initiated at the rapid filling phase of diastole by the ECG-triggered injection delay control to achieve complete mixing of the dye with blood. Anterior - posterior (ap) and lateral (lat) ventricular projections were obtained for both techniques with the patient in the supine position and recorded side by side at 50 frames/s on video tape (Grundig, Fuerth). For calibration purposes a steel sphere of known diameter was filmed at the location occupied by the respective ventricle. Suspended respiration, in order to minimize diaphragmatic movement and obstruction of the heart by the diaphragm was only achieved in older children. For the standard CA the x-ray - video - system (Siemens Pandoros) was run at 74 KV (62-88 KV)/165 mAs (87-260 mAs) in the ap plane and 77 KV (64-92 KV)/165 mAs (87-260 mAs) in the lateral plane and for DSA at 64 KV (58-75 KV)/123 mAs (62-234 mAs) and 71 KV (60-90 KV)/123 mAs (62-234 mAs) respectively. The largest projections were assumed to represent enddiastole (ED) and the smallest endsystole (ES); for DSA ECG triggering was used. The utilized system to obtain DSA has been described in detail before (1). For background subtraction a cardiac cycle is selected at a diaphragmatic level similar to the best opacified cycle (or the second post extrasystolic beat) of the ventricular filling phase. ED and ES frames as well as the preceeding and following frames of the selected background and opacified cycles were digitized (one television field: 256x256 pixels at 256 gray levels) and stored on digital disc (80 Mbyte=1225 images). The gray level of each pixel was logarithmically converted and averaged for the 3 background and the 3 opacified frames. After subtraction of the background image from the opacified image linear rescaling was performed in order to match the 256 gray levels of the output device. The selected angiocardiographic ED and ES frames were also digitized and stored on disc.

Measurements. Biplane ventricular projections obtained by both techniques were assessed in an identical manner. The utilized technique has been reported in detail before (8). Displayed on a TV monitor side by side the biplane silhouettes (steel sphere and ventricles in sinus beats) were traced by two independent observers (A and B) using a resistance foil and stored in a digital computer (PDP 11/60). In addition to biplane outlines five anatomically defined landmarks were marked, allowing e.g. the determinations of the long ventricular axis between the center of the semilunar valve ring and the apex. To minimize memory bias 4 days to 4 months elapsed between the interpretations of the angiocardiogram of a single patient. Ventricular volumes at ED and ES were calculated with the multiple sclices (RV) and area-length (LV) methods. In order to correct for different ventricular spatial orientations and shapes, the volumes were corrected with factors appropriate for position and cardiac phase (4,5,8). For the regional assessment a hemiaxis and a radial reference system (Fig.1) was used.

Analysis of data. A least squares regression analysis was used to compare volume parameters, obtained by both techniques. Significances of differences were calculated, using the paired t-test.

Results

The enddiastolic volume (EDV) determined by CA (RV/LV) ranged from 7/7 ml to 204/248 ml, the endsystolic volume (ESV) from 2/3 ml to 122/91 ml, the stroke volume (SV=EDV-ESV) from 5/4 ml to 86/157 ml, and the ejection fraction (EF=SV/EDV) from 0.25/0.52 to 0.71/0.88 Inter- and intraobserver variability for EDV/DSA was excellent achieving correlation coefficients (RV/LV) of r=0.998/0.996 and r=0.999/0.994 respectively (table 1 and 2). Analysis of EDV, ESV and SV by both techniques showed correlation coefficients (RV/LV) of 0.995/0.988, 0.988/0.992 and 0.983/0.975 respectively and standard errors of 5.7/9.6, 4.9,/2.6, and 5.2/9.2, respectiveley (Fig.2, table 1 and 2). There was no significant difference between the lines of identity and the regression lines as well as between EF, determined by both techniques (table 1 and 2). Regional analysis of ap and lateral projections showed no significant differences for all segmental areas, obtained with the radial (Fig.1) or the hemiaxis reference system. In general the standard error was smaller for the radial reference system (Fig.1).

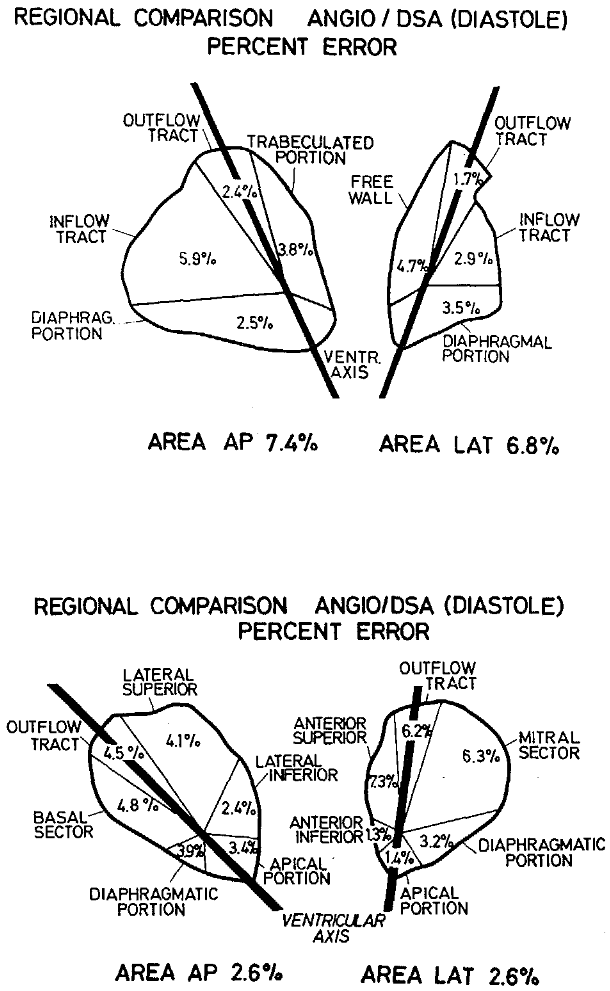

Figure 1: Regional comparison between conventional (Angio) and digital subtraction (DSA) angiocardiography of the right (upper panel) and the left (lower panel) ventricle.
% = percent error.

	n	a	b	sy/x	r
OBSERVER:A ANGIO / DSA					
EDV:	20	0.48	1.010	10.0	0.986
ESV:	20	2.21	0.929	6.7	0.981
SV:	20	3.08	0.986	10.3	0.933
EF:	20	mean=0.009+0.048			ns
OBSERVER:B ANGIO / DSA					
EDV:	20	1.77	0.995	5.7	0.995
ESV:	20	2.74	0.925	4.9	0.988
SV:	20	0.62	1.030	5.2	0.983
EF:	20	mean=-0.004+0.072			ns
Interobservervariability ANGIO: A / B					
EDV:	20	0.99	0.991	6.0	0.995
ESV:	20	0.52	0.967	3.8	0.994
SV:	20	-0.37	0.970	8.0	0.956
EF:	20	mean=0.012+0.049			ns
Interobservervariability DSA: A / B					
EDV:	20	2.43	0.971	3.7	0.998
ESV:	20	1.59	0.950	5.0	0.988
SV:	20	-0.39	1.001	5.5	0.980
EF:	20	mean=-0.001+0.040			ns
Intraobservervariability ANGIO: B1 / B2					
EDV:	20	0.55	0.990	1.7	0.999
ESV:	20	0.57	0.994	2.1	0.998
SV:	20	-0.25	0.970	5.0	0.980
EF:	20	mean=-0.014+0.035			ns
Intraobservervariability DSA: B1 / B2					
EDV:	20	-1.45	1.015	2.7	0.999
ESV:	20	-0.23	1.030	3.0	0.996
SV:	20	-0.74	0.991	3.2	0.993
EF:	20	mean=-0.008+0.031			ns
OBSERVER A EDV + ESV: ANGIO / DSA					
	40	0.53	1.002	8.8	0.985
OBSERVER B EDV + ESV: ANGIO / DSA					
	40	1.53	0.970	5.5	0.994

Table 1: Comparison between right ventricular volume parameters obtained by conventional (Angio) and digital subtraction angiocardiography (DSA).

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	n	a	b	sy.x	r
OBSERVER A:	ANGIO / DSA				
EDV:	25	-2.97	1.074	11.2	0.984
ESV:	25	1.53	1.033	3.5	0.985
SV:	25	-3.86	1.071	9.6	0.977
EF:	25	mea n = 0.019+0.037			ns
OBSERVER B:	ANGIO / DSA				
EDV:	25	-1.96	1.054	9.6	0.988
ESV:	25	0.44	1.107	2.6	0.992
SV:	25	-1.65	1.024	9.2	0.979
EF:	25	mea n = 0.020+0.043			ns
Interobserver variability ANGIO: A / B					
EDV:	25	0.50	0.997	4.2	0.998
ESV:	25	2.24	0.967	3.2	0.984
SV:	25	-0.44	0.987	5.9	0.991
EF:	25	mea n = 0.018+0.037			ns
Interobserver variability DSA: A / B					
EDV:	25	2.29	0.982	5.5	0.996
ESV:	25	1.38	0.993	3.1	0.989
SV:	25	1.74	0.964	4.0	0.996
EF:	25	mea n = 0.012+0.027			ns
Intraobserver variability ANGIO: B1 / B2					
EDV:	25	-1.07	1.018	5.6	0.996
ESV:	25	1.53	0.935	3.3	0.984
SV:	25	-2.47	1.048	5.3	0.993
EF:	25	mea n = 0.006+0.030			ns
Intraobserver variability DSA: B1 / B2					
EDV:	25	2.06	0.985	6.7	0.994
ESV:	25	-0.42	1.022	2.9	0.989
SV:	25	2.36	0.972	5.3	0.993
EF:	25	mea n =-0.005+0.028			ns
OBSERVER A EDV + ESV: ANGIO/DSA					
	50	0.15	1.044	8.3	0.989
OBSERVER B EDV + ESV: ANGIO/DSA					
	50	0.73	1.037	7.1	0.992

Table 2: Comparison between left ventricular parameters obtained by conventional (Angio) and digital subtraction angiocardiography (DSA).

Discussion

Comparison with previous studies. Our results indicate that left as well as right ventricular angiocardiograms obtained with direct injection of a reduced amount of contrast medium at a reduced flow rate and displayed with the aid of the digital subtraction technique (DSA) provide volumetric and global functional information comparable with that obtained from conventional intraventricular contrast angiocardiography (CA) (Table 1 and 2, Fig. 2). DSA allows visualization of the complete right and left ventricular cavity despite reduction of contrast medium to 30% and 35%, respectively of CA, at a flow rate diminished to 50% and 55% respectively of CA, with the same accuracy which has been found for the left ventricle after direct and intravenous injection (3,6,7,9,10). The reported correlations between CA and DSA with r-values between 0.82 and 0.98 for enddiastolic (EDV) and endsystolic (ESV) volumes (3,6,7,9,10) are similar to those obtained for the complex right ventricle (Table 1). This fact is even more surprising since our studied group of patients include a wide array of congenital pre and postoperative heart diseases with quite different sizes and shapes of right ventricle. In addition suspended respiration could not be achieved in most children, inducing motion artefacts. As was noted in most studies of left ventricle (3,6,7,9) we did not find significant under- or overestimation of volumes and derived parameters (Table 1 and 2, Fig. 2), if CA is accepted as the "gold standard". Moreover variations in results of the magnitude noted in our study are within the range reported by Chaitman et al. (2) for interobserver variability in analysis of a single left ventricle cineangiogram. Thus, although it is possible that differences in results are attributable to imprecision or systematic erros inherent in DSA of the right and left ventricle such inaccuracies are probably of a magnitude not exceeding that of inter and intraobserver variability (Table 1 and 2).

Benefits of digital subtraction angiocardiography for assessing ventricular function. There are several benefits of this digital angiocardiographic technique for assessing ventricular size and function. First, only 30% and 35%, respectively of contrast medium used for CA was required to obtain adequate visualization of ap and lateral projections. This is especially important for small babies with complex congenital heart defects since hemodynamic and toxic side effects of the contrast medium will be diminished. A second advantage of the technique is that only 50% and 55%, repectively of the flow rate utilized for CA was necessary. Both the reduction of contrast medium and flow rate will decrease recoil of the injection catheter thus probably being responsible for the considerable lower incidence of ventricular ectopy of DSA. No PVC´s were observed in 68% and 79%, respectively of DSA and 37% and 34%, respectively of CA. Another benefit of this DSA is the somewhat smaller x-ray energy level to which infants and children are exposed, being 75% and 88%, respectively of CA. It probably can be reduced further with additional experience with this technique. DSA series can be shortened considerably. Thus DSA enables the utilization of multiple injections during the monitoring of physiologic and potential therapeutic interventions. Diagnosis of tricuspid insufficiency may be possible by this method, since recoil of the catheter resulting in artificial atrio-ventricular valve insufficiency seems to be preventable in most cases. Another advantage of DSA is the ability to easily postprocess the video image and improve contrast visualization for boundary detection. Postprocessing images in this manner may obviate some of the problems with traditional cine film developing, such as poor quality control or erratic film processing. Whether DSA can be developed to the point, where it could replace cine film entirely howewer necessitates further evaluation.

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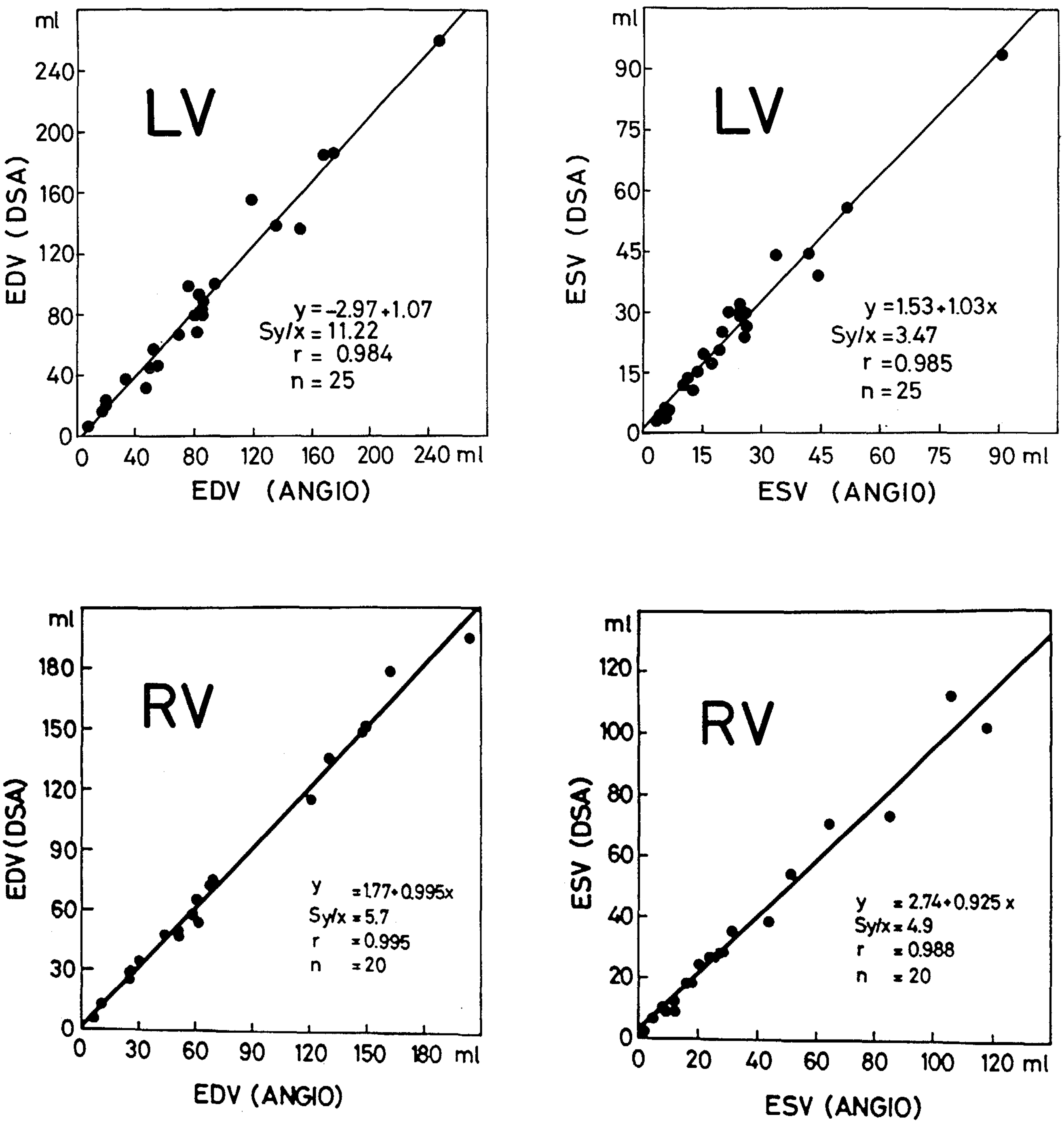

Figure 2:
Enddiastolic (EDV) and endsystolic (ESV) volume of the left (LV) and right (RV) ventricle as determined by conventional (Angio) and digital subtraction (DSA) angiocardiography.

Difficulties and limitations of digital subtraction angiocardiography of the right and left ventricle. We encountered several problems in obtaining high quality angiocardiograms of the right and left ventricle using DSA. Breathing during the study created a mismatch between the background soft tissue densities obtained in the mask and soft tissue densities obtained during the passage of the contrast medium. To match corresponding background frames repeat replay of the video series was necessery. Further research is necessary to minimize this limitation, since prevention of respiration during the study is not possible in sedated infants and children. Furthermore it is important that the tip of the injection catheter is located close to the apex, otherwise complete opacification of the entire ventricle is difficult to achieve. Spatial resolution necessary for the exact morphologic diagnosis of congenital heart disease is difficult to obtain with DSA at the present time. However, multiple angulated views of the heart, often required during cardiac catheterization can be obtained with less side effects. To define the regional accuracy of DSA is difficult, since there are no significant differences between DSA and CA for the analyzed regions. A disadvantage is the invasiveness of our approach. However, the used Seldinger technique is a very safe method, which is utilized by most authors reporting on intravenous DSA of the left ventricle (3,6,7,10).

Conclusions

Biplane digital subtraction angiocardiography of the right and left ventricle after direct injection of contrast medium allows accurate determination of ventricular size and global function in infants and children with congenital heart disease. The main benefits of this method are reduction of contrast medium, flow rate during injection, x-ray radiation, and ventricular ectopy. The easy repeatability of this method allows its application during monitoring of physiologic and potential therapeutic interventions. The main disadvantage of this invasive method is that respiration should be suspendend, which is difficult to achieve in sedated children.

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