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IMPROVEMENT OF 2D-ECHO VOLUME DETERMINATION OF THE RIGHT VENTRICLE BY IMAGE ENHANCEMENT AND INJECTION OF CONTRAST MEDIA. - AMELIORATION DE LA DETERMINATION PAR ECHO BIDIMENSIONAL DU VOLUME DU VENTRICULE DROIT PAR REHAUSSEMENT D'IMAGE ET INJECTION DE PRODUIT DE CONTRASTE.

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RESUME

Afin de déterminer les facteurs influencant l'exactitude des paramètres du volume du ventricule droit, obtenus par l'échocardiographie et pour améliorer les relevés donnes en appliquant des méthodes de rehaussement d'image, on a effectué une échocardiographie quantitative de contraste et une angiocardiographie biplane pendant l'examination de routine de cathétèrisation cardiaque chez 23 enfants. Les volumes obtenus sur la base des sections transversales d'échocardiographie (area-length method et volume sphèrique), traités et non-traités, montrerent une sous-éstimation des volumes angiocardiographiques ($p<0.01$) (méthode a tranches multiples) plus prononcée en fin de diastole (50.6%) qu'en fin de systole (35.9%). De la même facon, les fractions d'éjection furent sous-estimeés, les moyennes furent 0.480 ± 0.12, respectivement 0.595 ± 0.77. Les coefficients de corrélation pour la comparaison des volumes d'angio et d'echo fin diastolique et fin systolique furent r=.968/.945, r=.976/.959 et r=.974/.946 pour la prise de vue échocardiographique non traitée et respec- tivement pour la prise de vue traitee en employant la valeur moyenne et pour la prise de vue de l'écho avec contraste, traitée avec la soustraction numerique. Avec les six méthodes de rehaussement d'image utilisées, on atteint une structure de la prise de vue plus homogène et une representation plus distinct de la surface interne. L'erreur statistique ne s'améliora qu'un peu.

La vue échographique de 4 chambres permet la détermination du volume du ventricule droit avec une exactitude acceptable. La sous-estimation des volumes angiocardiographiques est due a une visualisation inadéquate des trabéculations et particulièrement due au modele utilise. L'application des techniques amélioratives de la prise de vue permet une représentation de la surface de la cavité interne plus simple et plus rapide. L'avantage atteint par la combinaison de l'injection d'un medium de contraste et des méthodes amélioratives de prise de vue ne justifie pas une injection par voie centrale comme méthode de routine considérant les produit de contraste disponibles en ce moment.

SUMMARY

To determine factors which influence the accuracy of echocardiographically estimated volume parameters of the right ventricle and to improve the echocardiographic input information by applying image enhancement techniques, quantitative contrast echocardiography (4-chamber view) and biplane angiocardiography were performed in 23 children during routine diagnostic heart catheterization.

Volumes calculated on the basis of unprocessed and processed echocardiographic cross-sections (area-length method and sphere volume) underestimated angiocardiographic volumes (multiple slices method) significantly ($p<0.01$) more in enddiastole (50.6%) than in endsystole (35.9%). Also the ejection fraction was significantly ($p<0.01$) underestimated, the mean values being $.480 \pm .12$ and $.595 \pm .77$, respectively. Relating angio and echo volumes the correlation coefficients for enddiastole/ endsystole were r = .968/ .945, r = .976/ .959, and r = .974/ .946 for the unprocessed echocardiographic image, the processed image using the median value, and processed image plus digital subtraction of contrast echo, respectively. With six different utilized image enhancement techniques a more homogeneous structure of the image and a more distinct outline of the internal surface was achieved. The statistical error improved only slightly.

The echocardiographic 4-chamber view allows volume determination of the right ventricle with an acceptable accuracy. Underestimation of angiocardiographic volumes is related to inadequate visualization of trabeculations and mainly to the model used. Application of image enhancement techniques allows easier and faster outlining of the internal cavity surface. The advantage gained by the combination of contrast injection and image enhancement techniques does not warrant the routine central injection of available contrast material.

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IMPROVEMENT OF 2D-ECHO VOLUME DETERMINATION OF THE RIGHT VENTRICLE BY IMAGE ENHANCEMENT AND INJECTION OF CONTRAST MEDIA. - AMELIORATION DE LA DETERMINATION PAR ECHO BIDIMENSIONAL DU VOLUME DU VENTRICULE DROIT PAR REHAUSSEMENT D'IMAGE ET INJECTION DE PRODUIT DE CONTRASTE.

Introduction:
Knowledge of the functional state of the right ventricle before and after corrective as well as palliative surgery of congenital heart diseases is of great clinical importance. Quantitative angiocardiography is regarded the most accurate method for this purpose, but it is an invasive technique. 2D-echocardiography as non-invasive method appears promising, quantitative studies, however, yielded only fair results (1,5,8,12,13,14). Exact determination of the accuracy of echocardiographic volume determination of the right ventricle with right ventricular casts, the classic model for the assessment of angiocardiographic volume determination (4,6) does not seem to be possible, since presently available casting materials do not allow a sufficient echocardiographic visualization of a cross section (1,12) Most studies therefore assess the accuracy by comparison with the biplane angiocardiographic method (5,8,12,13,14), which is regarded to be the most readily available and most reliable in vivo technique for this purpose.
To determine factors which influence the accuracy of echocardiographically determined volume parameters and to improve the echocardiographic input information by the application of digital image enhancement techniques quantitative contrast echocardiography (4-chamber view) and biplane angiocardiography were performed in 23 patients during routine diagnostic cardiac catheterization.
Methods
Study patients: 23 patients undergoing routine diagnostic catheterization for clinical indicated reasons were studied including 8 patients between 1 and 5 years, 5 between 5 and 10 years, 4 between 10 and 15 years, and 6 between 15 and 20 years. Their age ranged from 1 to 20 years (mean 9.2 year), their length from 80 to 175 cm (mean 130 cm), their weight from 9 to 72 kg (mean 31 kg), and their body surface area from .46 to 1.90 m^2.
Diagnoses included: patent ductus arteriosus (n=2), pre- and postoperative tetralogy of Fallot (n=3), simple transposition of the great arteries (n=2), aortic stenosis and insufficiency (n=2), ventricular septal defect and pulmonary stenosis (n=2), atrial septal defect (n=6), coarctation of the aorta (n=3), pulmonary stenosis (n=2), and no congenital heart disease (n=1).

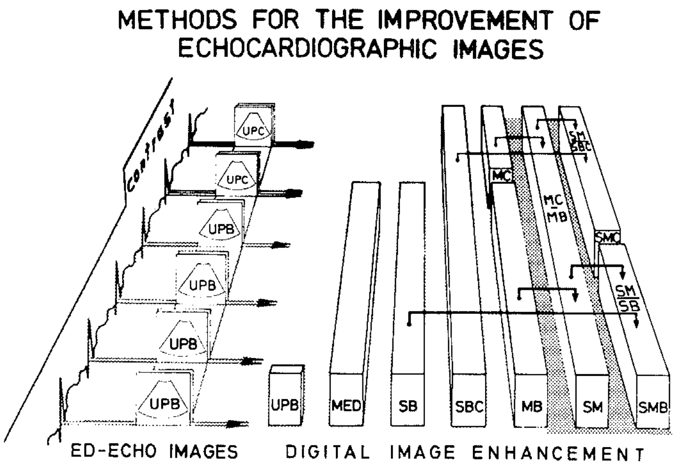

Fig. 1: Schematic representation of the 6 methods (MED, SB, MB, SM, SMB, SMC) utilized for digital enhancement of TV-images of 2D-echo series. UPB: unprocessed background, UPC: unprocessed contrast, MED: median value, SB: standard deviation of the UPB, SBC: standard deviation of UPB plus UPC, MB: mean value of UPB, MC: mean value of UPC, SM: MC-MB, SMB: SM/SB, SMC: SM/SBC. Contrast: cold normal saline and 5% glucose, injected into superior vena cava, right atrium, and right ventricle.

Cardiac catheterization was performed with local lidocaine anesthesia under sedation (10 mg/kg acidum phenylbarbituricum), 1-1.5 mg/kg pethidine and 0.01-0.015 mg/kg atropine). All patients underwent standard biplane angiocardiography before echocardiography.
Data acquisiton: Conventional angiocardiography (Siemens, Pandoros) and contrast 2D-echocardiography (Roche RT 400, 2.8 and 3.5 MHZ) were performed with a 6F or 7F Berman catheter inserted into the femoral vein, using a modified percutaneous Seldinger technique. For angiography 1 ml/kg (ECG-triggered in diastole) diatrizoate meglumine (Urografin, Schering, Berlin) at 10 to 25 ml/s (mean: 17 ml/s) (Contrac, Siemens) and for echography 5 to 10 ml cold 5% glucose or normal saline (by hand) were injected into the right ventricle (RV), right atrium (RA), or superior vena cava (SVC), the patient being in supine position. Biplane angiocardiographic right ventricular projections as well as the echocardiographic 4-chamber view were recorded at 50 frames/s on video-tape (Grundig, Fürth) together with ECG and identification number. For calibration purposes a steel sphere of known diameter was filmed at the location occupied by the RV during angiocardiography. Suspended respiration in order to minimize movement artefacts was only achieved in older children.
Image enhancement: For digitization of the echocardiographic series, stored on video-tape, a 256x256 pixel, 8 bit gray level matrix was used ECG-gated enddiastolic and endsystolic background as well as contrast frames were transfered to a standard digital disc (DEC RP04, 80 Mbyte) linked to a minicomputer (DEC PDP 11/40). Details of the digital image processing equipment and techniques for enhancement have been described elsewhere (2).
Only those images were chosen for further processing which correlated well with all other images in the group to be averaged. Details of the averaging technique utilized are schematically shown in fig. 1.
With reference to the ECG 2 images around enddiastole and endsystole of 4 subsequent background and 3 of 2 subsequent contrast cardiac cycles were selected. Thus for both cardiac phases at each location of the image 8 background and 6 contrast echo amplitudes per pixel could be extracted for further processing. Such a set of amplitude samples was used to derive a representative gray level for each pixel of the background frames calculating: (1) mean value (MB), (2) standard deviation of the sample (SB) by calculating the square root of the mean squared deviation from the mean, (3) median value (MED) by sorting the N samples contained in the measurement sample in descending order and than selecting the value at position N/2 ((N+1)/2 for N = odd).
For contrast frames the mean (MC) and for the 8 background plus 6 contrast frames together the standard deviation (SBC) was calculated. The following subtraction techniques were used: (1) SM = MC - MB; (2) SMB = SM/SB; (3) SMC = SM/SBC;
Measurements: Biplane angiocardiographic projection and the echocardiographic cross-sections were assessed in a similar manner. The utilized technique has been described before (9,10). Displayed on a TV-monitor the biplane projections (steel sphere and ventricles in sinus beats) and echocardiographic cross sections were traced with an x/y coder using a resistance foil and stored in a mini computer (DEC PDP 11/60). In addition to the ventricular outlines anatomically defined internal landmarks (fig. 2) were marked and stored the same way. For calibration of the echographic image a built-in system of defined distances was used.
Angiocardiographic right ventricular volumes were calculated with the biplane multiple slices method, the model volumes being corrected with factors appropriate for spatial orientation and cardiac phase (6). The spatial ventricular axes between the center of the pulmonary valve ring and the apex as well as between tricuspid valve and apex were calculated on

the basis of the respective landmarks (fig.2). The mean diameter (MDA) is defined as the radius of the sphere with the angiocardiographic volume of the right ventricle, obtained with the area-length method. The echocardiographic volumes were calculated in two ways: (1) $V = (\pi/6)\ MDE^3$, where MDE is the diameter of the circle with the area (F) of the echographic cross-section. It is assumed that the right ventricle is a sphere; (2) $V = (3/8\pi)\ F^2/L$, where F is the area of the echographic cross-section and where L is the distance between the tricuspid valve (T) and the trabeculated portion (R) (fig.2). To characterize the shape L was devided by MDE.

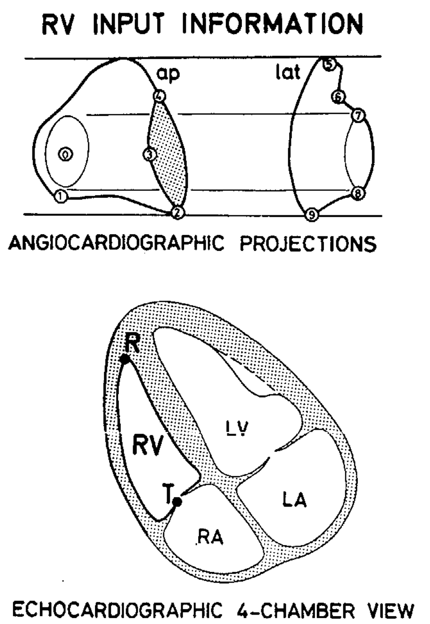

Fig.2: Schematic representation of the angiocardiographic (upper panel) and echocardiographic (lower panel) input information. Numbers of the angiocardiographic projections and letters of the 4-chamber view refer to anatomic landmarks stored in the computer for further processing.

The difference between enddiastolic (EDV) and endsystolic (ESV) volume is the stroke volume (SV) and the ratio SV/EDV the ejection fraction (EF).

Results

Out of 35 patients in whom angiocardiography and echocardiography was performed 23 were included in this study. The reasons for exclusion were PVC's during angiocardiography in 1, precluding adequate opacification of the second postextrasystolic beat, technical malfunction of the video-tape in 4, and inadequate contrast of the echographic right ventricular cross-section in 7 patients. EDV determined by angio ranged from 26.2 to 246.4 ml, ESV from 8.5 to 9.53 ml, SV from 17.6 to 155.6 ml and EF from 0.42 to 0.7 (fig.3). Results of the regression analysis of the relationships between angiocardiographic volumes as reference and the different echocardiographic volumes are summarized for sphere volumes in table 1 and area-length volumes in table 2. Volumes calculated on the basis of processed as well as unprocessed echocardiographic cross-sections underestimated the angiocardiographic volumes significantly ($p<0.01$) and this significantly ($p<0.01$) more in enddiastole than in endsystole (table 1 and 2, fig.3). Echo (UPB) underestimated the angio EF significantly ($p<0.01$), the mean values being .480 ±.120 and .595 ±.077, respectively. Echo (UPB) and angio EF correlated with r = .548.

With all utilized image enhancement techniques a more homogeneous structure of the image and a more distinct outline of the internal surface of the cavity was achieved (fig.4). Correlating echo and angio volumes the lowest statistical errors were observed using the median value (r = 0.976) and contrast echo after background subtraction using SMB (r = 0.974). Relating angio and echo volumes, the latter being calculated on the basis of (a) the long axis TR (fig.2) of the cross-section, (b) the area of the cross-section as well as (c) area and long axis TR, the lowest statistical error was found for (b) and (c) and the highest for (a) (table 4). The shape of the echocardiographic cross-section (4-chamber view, UPB) expressed as ratio long axis TR/MDE was slightly more circular in endsystole than in enddiastole, but this difference did not reach statistical significance (table 3). By contrast the spatial angiocardiographic

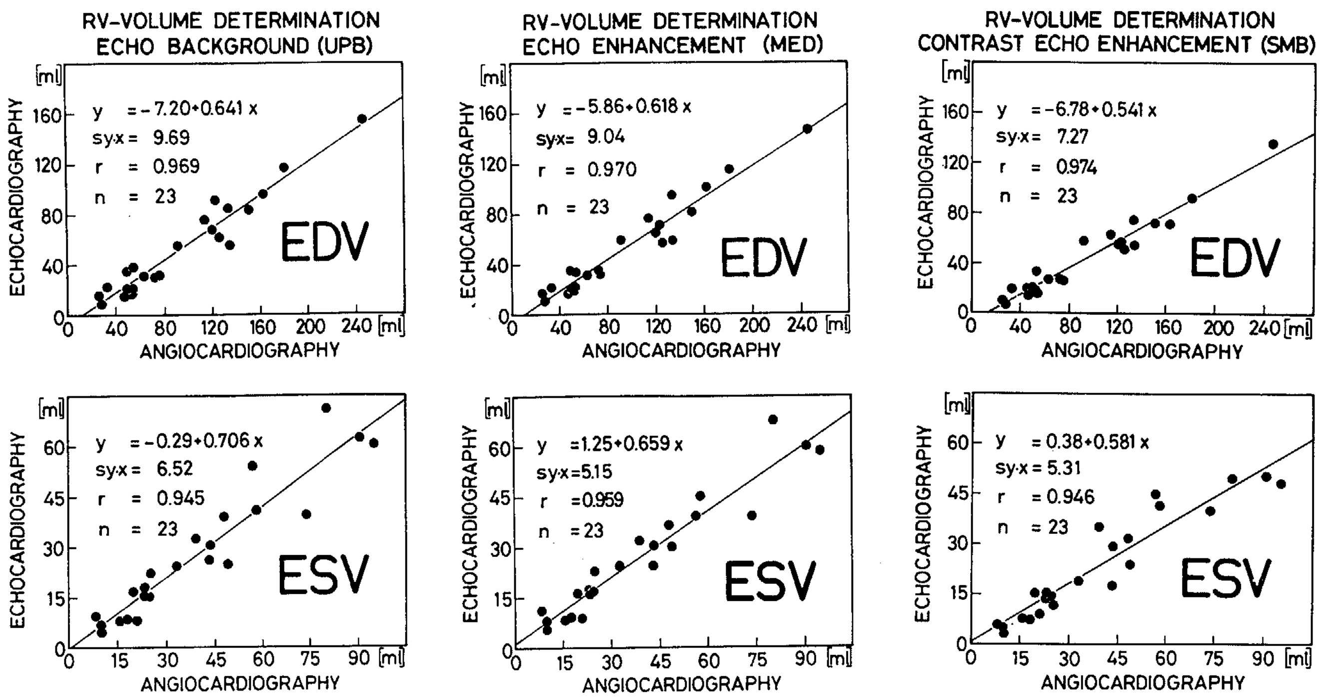

Fig.3: Relationship between enddiastolic (EDV) and endsystolic (ESV) volumes, determined by angiocardiography and by 3 different echocardiographic techniques; Abbreviations: fig.1.

shape expressed as ratio axis pulmonary valve - apex/MDA and axis tricuspid valve - apex/MDA was significantly (p<0.01) less spherical in endsystole (table 3).

Discussion

Systematic error: Our results indicate that 2D-echocardiography underestimates angiocardiographic volumes significantly (table 1 and 2, fig.3).
This seems to be related to the complex geometry of the right ventricle, which consists of the three compartments inflow tract, outflow tract and trabeculated portion. The echocardiographic information gained by using the 4-chamber view (fig.2 and 4), however, is only one cross-section of inflow tract and trabeculated portion. It is not surprising that calculation based on this typical triangular shaped cross-section underestimates total right ventricular volume if an ellipsoid model as in the area-length method is used (table 1 and 2, fig.3).
Adjusting the model - a mathematical maneuver to prevent under- or overestimation (5) - does not improve the accuracy of the method. The input information - the main factor determining the accuracy of the method - remains unchanged.
The angiographic outline of the right ventricle includes contrast medium within the trabeculated portion as well as within the trabeculae carnae, since the muscle bundles are surrounded by the contrast medium. The echocardiographic outline probably represents in many instances the innermost portions of the trabeculations, owing to the finite resolution of the echocardiographic beam. It is limited lateral as well as perpendicular to the scanning plane (10). The lateral effect was pointed out by Schnittger et al. (11) for the left ventricle and results in a cavity outline that is inside the angiocardiographic border. It is especially obvious for the trabeculated portion. Only a very small part is included within the outline of the cavity.
The non simultaneous recording of angiocardiogram and echocardiogram could result in a larger angiographic volume, since the flow increases after the injection of angiographic contrast medium into the right ventricle. The maximum was observed 3 to 5 beats after the beginning of the injection and the flow remains elevated at least 20 minutes after the injection of diatrizoate (Urografin, Schering AG) (7). This is the time during which the echocardiographic recording was performed in all our patients.
Echocardiographic underestimation of the angiocardiographic volume was significantly (p<0.01) less in endsystole than in enddiastole, the mean ratio echo/angio volume being 28% higher in endsystole. With the exception of Silverman et al. (13) such a difference has not been reported (5,8,14). It may be related in part to the different factors used for correction of the angiocardiographic model volumes. We are the only ones who utilized different factors for enddiastole and endsystole, the latter being approximately 15% smaller than the former (6).

	a	b	r	sy.x
	ANGIO - ECHO (UPB)			
EDV:	-7.20	0.641	0.968	9.69
ESV:	-0.29	0.706	0.945	6.52
SV:	-5.14	0.562	0.923	7.98
EF:	diff.=-0.114 ±0.101 p<0.001			
	ANGIO - ECHO (MB)			
EDV:	-6.91	0.606	0.967	9.23
ESV:	0.33	0.649	0.954	5.45
SV:	-5.46	0.543	0.922	7.73
EF:	diff.=-0.118 ±0.098 p<0.001			
	ANGIO - ECHO (SB)			
EDV:	-5.48	0.567	0.969	8.35
ESV:	1.20	0.563	0.958	4.47
SV:	-4.30	0.528	0.932	6.97
EF:	diff.=-0.092 ±0.091 p<0.001			
	ANGIO - ECHO (MED)			
EDV:	-5.86	0.618	0.976	9.04
ESV:	1.25	0.659	0.959	5.15
SV:	-5.34	0.557	0.931	7.42
EF:	diff.=-0.126 ±0.092 p<0.001			
	ANGIO - ECHO (SM)			
EDV:	-5.89	0.568	0.939	12.06
ESV:	0.54	0.617	0.941	5.94
SV:	-6.15	0.528	0.873	10.00
EF:	diff.=-0.128 ±0.137 p<0.001			
	ANGIO - ECHO (SMB)			
EDV:	-6.78	0.541	0.974	7.27
ESV:	0.38	0.581	0.946	5.31
SV:	-6.80	0.506	0.931	6.71
EF:	diff.=-0.123 ±0.100 p<0.001			
	ANGIO - ECHO (SMC)			
EDV:	-4.65	0.542	0.969	8.02
ESV:	0.81	0.605	0.955	5.03
SV:	-5.43	0.496	0.935	6.37
EF:	diff.=-0.127 ±0.108 p<0.001			

Tab.1: Regression analysis y=a+bx of RV-volume parameters (n=23) determined by angiocardiography (angio: x) and echocardiography (echo: y) pre and post application of different image enhancement methods (Abbreviations: fig. 1). Echo volume determination assumes a sphere; diff.=mean difference: Echo-EF minus Angio-EF.

	a	b	r	sy.x
	ANGIO - ECHO (UPB)			
EDV:	-5.37	0.495	0.946	9.79
ESV:	-0.04	0.578	0.952	4.95
SV:	-2.89	0.391	0.885	6.97
EF:	diff. = -0.155±0.109; p<0.001			
	ANGIO - ECHO (MB)			
EDV:	-5.83	0.473	0.948	9.17
ESV:	-0.04	0.535	0.954	4.49
SV:	-3.94	0.395	0.877	7.34
EF:	diff. = -0.154±0.108; p<0.001			
	ANGIO - ECHO (SB)			
EDV:	-4.06	0.435	0.941	9.10
ESV:	1.26	0.444	0.943	4.17
SV:	-3.01	0.386	0.868	7.51
EF:	diff. = -0.168±0.159; p<0.001			
	ANGIO - ECHO (MED)			
EDV:	-5.52	0.492	0.950	9.40
ESV:	1.05	0.528	0.960	4.15
SV:	-4.10	0.422	0.862	8.44
EF:	diff. = -0.126±0.120; p<0.001			
	ANGIO - ECHO (SM)			
EDV:	-4.83	0.443	0.916	11.24
ESV:	0.32	0.507	0.938	5.01
SV:	-4.24	0.381	0.815	9.22
EF:	diff. = -0.156±0.120; p<0.001			
	ANGIO - ECHO (SMB)			
EDV:	-5.83	0.424	0.961	7.08
ESV:	0.33	0.468	0.957	3.80
SV:	-5.27	0.377	0.887	6.65
EF:	diff. = -0.177±0.137; p<0.001			
	ANGIO - ECHO (SMC)			
EDV:	-4.21	0.420	0.956	7.49
ESV:	0.82	0.490	0.966	3.47
SV:	-4.69	0.364	0.877	6.77
EF:	diff. = -0.157±0.119; p<0.001			

Tab.2: Regression analysis y=a+bx of RV-volume parameters (n=23) determined by angiocardiography (angio:x) and echocardiography (echo:y) pre- and post application of different image enhancement methods (Abbreviations: fig.1). Echocardiographic volumes were calculated with the area-length method; diff.= mean difference echo-EF minus angio-EF.

	Angio: PA/MDA
ED	= 1.362 ±0.108
ES	= 1.445 ±0.108
ED-ES	= -0.083 ±0.101 (p<0.001)
	Angio: TA/MDA
ED	= 1.125 ±0.115
ES	= 1.190 ±0.147
ED-ES	= -0.065 ±0.113 (p<0.01)
	Echo: TR/MDE
ED	= 1.321 ±0.152
ES	= 1.261 ±0.129
ED-ES	= 0.059 ±0.161 (ns)

Tab.3: RV shape parameters; PA: spatial distance pulmonary valve-apex; TA: spatial distance tricuspid valve-apex; TR: distance tricuspid valve-apex in the echocardiographic cross-section; MDA: mean diameter equal to the diameter of the sphere with the angiographic area-length volume; MDE: mean diameter equal to the diameter of the circle with echographic area.

Echovolume: Length TR
ED: r = 0.914 v = 30.7%
ES: r = 0.786 v = 53.1%
Echovolume: Area F
ED: r = 0.968 v = 18.0%
ES: r = 0.945 v = 23.5%
Echovolume: Area-Length
ED: r = 0.946 v = 23.5%
ES: r = 0.952 v = 21.6%

Tab.4: RV-echovolume versus angiovolume.

Assessing the shape of the echocardiographic cross-section it appears likely that the enddiastolic/endsystolic echocardiographic information differs from the angiocardiographic one. The 2-dimensional ratio length of the cross-section/MDE as shape parameter does not change significantly in enddiastole and endsystole (table 3). In contrast the angiographic spatial ratio length of the axis tricuspid valve/MDA indicates a less spherical shape in endsystole (table 3). Little of the trabeculated portion and more of the inflow/outflow tract is visualized echographically thus preventing quantitation of its changes during the cardiac cycle. An additional factor could be the systolic movement of the apex caudally and to the left with respect to the pulmonary and tricuspid valves as well as with respect to the echotransducer.

Statstical error: The statistical errors found relating echo and angio volumes (fig.3, table 1 and 2) compare favorably with those reported in the literature (5,8,12,13,14), being at least as low as those found for the left ventricle (3,11). This is surprising since the input information of the complex internal geometry obtained with the 4-chamber view is small (fig.4). The low statistical error (table 1 and 2, fig.3) indicates that the shape of the right ventricle is rather constant and that the 4-chamber view is comparably well reproducable, correcting for the different spatial orientations of the right ventricle in patients with different congenital heart diseases, a variety of which being included in this study. Attempts to increase the input information by using biplane echographic views (8,13,14) failed. Standardization of these views does not appear possible. The gained information cannot compete with that of standard biplane angiocardiographic projections of the right ventricle. Reducing the input information to a single "standard dimension", as has been proposed by Bommer et al. (1) on the basis of cast studies, does not seem to be appropriate. Using the area of the cross-section in order to calculate right ventricular volumes resulted in significantly lower statistical errors (table 1 and 4) than those, if just the axis TR was utilized (fig.2, table 4), suggesting that a "standard dimension" of the 4-chamber view may vary considerably.

Background images: The noisy appearance and the often poor border definition of the right ventricular endocardial surface are limitations typical for 2D-echocardiographic images. To improve these limitations we derived mean value, standard deviation, and median value of the brightness of each pixel of 8 background images. With all three of these statistical methods a homogeneous structure of the image and a more distinct outline of the internal surface (fig.4) of the right ventricular cavity could be achieved in most cases. The location of this internal border, however, is different for the three methods. Structures of this region, which are not present on each of the processed images due to motion of heart and thorax or slight involuntary movement of the transducer, are processed differently the smallest area being observed after standard deviation and the largest after median value. Correspondingly the calculated volumes are different (table 1 and 2). If such enhancement techniques are used in order to make the outlining of the right ventricular cavity easier and faster, the same statistical method should be applied. In terms of statistical error the median value offers the highest correlation coefficient and the lowest scatter of data (table 1 and 2, fig.3).

Contrast echo and digital subtraction: Contrast echocardiography in order to outline the inner surface of the right ventricle is only useful in conjunction with background subtraction techniques (fig.1). Tracing the outline becomes even easier and faster than after the application of background enhancement techniques (fig.1). The achieved decrease of the statistical error was only slight (table 1 and 2). The main reason is probably the used contrast agents, cold normal saline or 5% glucose solution, which did not distribute homogeneously enough. Standardized microbubbles should improve this technique. As site of injection superior vena cava and right atrium proved to be preferable to right ventricle, necessitating on the average 1.8 injections versus 3 injections to achieve adequate filling of the right ventricle.

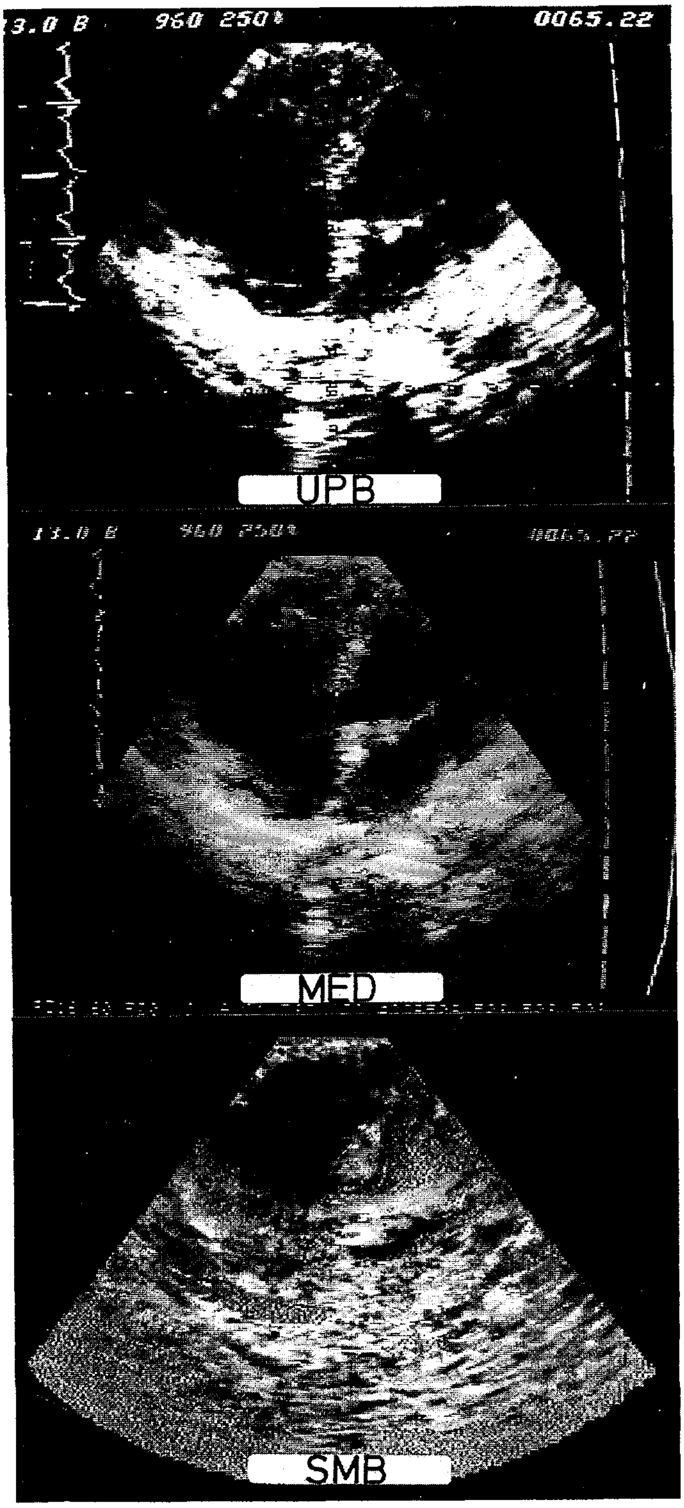

Fig.4: 2D-echocardiographic 4-chamber views. Upper panel: unprocessed background (UPB); middle panel: processed background, median value (MED); lower panel: contrast subtraction image (SMB) after injection of cold normal saline into the right ventricle. Abbreviations: fig.1.

Contrast echocardiographic volumes were consistently lower than non-contrast echocardiographic volumes (table 1 and 2), because in many regions the contrast agent did not reach the internal surface. A disadvantage of the presently used enhancement technique is the lack of a play back feature, which allows better border detection in some regions. Automatic border recognition does not appear possible at the present stage and is awaiting further development of echo machines and enhancement techniques. Standardized bubbles may also reduce or abolish this systematic difference.

Conclusions:

1. The echocardiographic 4-chamber view allows volume determination of the right ventricle with an acceptable accuracy.
2. Echocardiography underestimates angiocardiographic volumes and this more in enddiastole than in endsystole, which is related to inadequate visualization of trabeculations and to the model used.
3. The area of the echocardiographic cross-section is the most important input information for the calculation of volume data. Adding a length like in the area-length method does not improve the accuracy.
4. Application of image enhancement techniques to the echocardiographic image achieves a homogeneous structure and a more distinct border definition. The statistical error improves only slightly.
5. Contrast echocardiograms can only be evaluated quantitatively if image enhancement techniques are applied. Outlining the internal surface becomes easier and faster. The advantage gained, however, does not warrant routine central injection of available contrast media.

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