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

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Résumé

Afin de déterminer les facteurs influençant l’exactitude des paramètres du volume du ventricule droit, obtenus par l’échocardiographie et pour améliorer les relevés donnés en appliquant des méthodes de rehaussement d’image, on a effectué une échocardiographie quantitative de contraste et une angiocardiographie biplane pendant l’examen de routine de cathétérisation cardiaque chez 23 enfants. Les volumes obtenus sur la base des sections transversales d’échocardiographie (area-length method et volume sphérique), traités et non-traités, montrèrent une sous-estimation des volumes angiocardiographiques (p<0.01) (mêthode à tranches multiples) plus prononcée en fin de diastole (50.6%) qu’en fin de systole (35.9%). De la même façon, les fractions d’éjection furent sous-éstimées, les moyennes furent 0.480±0.12, respectivement 0.595±0.77. Les coefficients de corrélation pour la comparaison des volumes d’angle et d’écho 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 respectivement pour la prise de vue traitée en employant la méthode avec sous-estimation. La prise de vue échocardiographique utilisée, on attirent une structure de la prise de vue plus homogène et une représentation plus distinct de la surface interne. L’erreur statistique ne s’améliore qu’un peu. Le vêgètique d’4 chambres permet le détermination du volume du ventricule droit avec une exactitude acceptable. La sous-estimation des volumes angiocardiographiques est due à une visualisation inadéquate des trabéculations et particulièrement due au modèle utilisé. 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 média de contraste et des méthodes amélioratives de prise de vue ne justifie pas une injection par voie centrale comme méthode de routine considérant les produits de contraste disponibles en ce moment.

Sommaire

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 end systole (50.6%) than in end systole (35.9%). Also the ejection fraction was significantly (p<0.01) underestimated, the mean values being .480 ±.12 and .595 ±.77, respectively. Relating angio and echo volumes the correlation coefficients for end diastole/ end systole 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.
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 angiocardiology is regarded the most accurate method for this purpose, but it is an invasive technique. 2D-echocardiograph as non-invasive method appears promising. quantitative studies, however, yielded only fair results (1,5,8,12,13,14). Exact determination of the echocardiographic volume determination of the right ventricle (RV) is one of the most difficult problems in echocardiography. The classic model for the assessment of angiocardio- graphic volume determination (4,6) does not seem 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 blipane angiocardiogetic 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 (6-chamber view) and blipane angiocardiology were performed in 23 patients during routine diagnostic cardiac catheterization.

Methods

Study patients: 22 patients undergoing routine diagnostic catheterization for clinical indications were included in the study. In addition, 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 0 to 20 years (mean 9.2 years), 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 0.6 to 1.9 m². 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).

METHODS FOR THE IMPROVEMENT OF ECHOCARDIOGRAPHIC IMAGES

Cardiac catheterization was performed with local lidocaine anesthesia under sedation (10 mg/kg acium phenylbutarbucurium), 1-1.5 mg/kg pethidion and 0.01-0.015 mg/kg atropine. All patients underwent standard blipane angiocardiology before echocardiography.

Data acquisition: Conventional angiocardiology (Siemens, Pansidor) and contrast 2D-echocardiography (Rochte RP 400, 2.6 and 3.5 MHz) were performed with a 6F 7F German catheter into the femoral vein, using a modified parasternal short axis 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 echocardiography 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 (SCV), the patient being in supine position. Blipane angiocardographic right ventricular projections as well as the echocardiographic long axis and 6-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 angiocardiology. 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 endystolic background as well as contrast frames were transferred to a standard digital disc (DEC RP 40, 80 Mbyte) linked to a minicomputer (DEC PDP 11/40). Details of the digital image processing, edge detection and quantification techniques for enhancement have been described elsewhere (2). Only those images were chosen for further processing which were free of artefacts. Details of the averaging technique utilized are given in (12). 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 (background and contrast) 8 contrast echoamplitudes per pixel could be extracted for further processing. Such a set of amplitude samples was used to derive a representative grey 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 then selecting the value at position N/2 (N=1/2 for N odd).

For contrast frames the mean (MC) and for the contrast (n=5) frames together the standard deviation (SBC) was calculated. The following subtraction techniques were used: (1) SM = MC - MB; (2) SB = SM/MB; (3) SBC = SM/SCV. Measurements: Biplane angiocardigraphic 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 model volumes being corrected with factors appropriate for spatial orientation and cardiac phase (6). The spatial spatial ventricular axes between the center of the pulmonary valve ring and the apex as well as between tricuspid valves apex were calculated on
the basis of the respective landmarks (fig. 2). The mean diameter (MDE) is defined as the radius of the sphere, obtained with the area-length method. The echocardiographic volumes were calculated in two ways: (1) \( V = \frac{4}{3} \pi MDE^3 \), where MDE is the diameter of the circle with the area (F) of the echocardiographic cross-section. It is assumed that the right ventricle is a sphere; (2) \( V = \frac{3}{2} \pi \), where \( F \) is the area of the echocardiographic cross-section and \( L \) is the distance between the tricuspid valve (T) and the trabeculated portion (R). To characterize the shape, \( L \) was divided by MDE.

**RV INPUT INFORMATION**

**ANGIOCARDIOGRAPHIC PROJECTIONS**

**ECHOGRAPHIC 4-CHAIR VIEW**

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

**RV-VOLUME DETERMINATION**

**ECHO BACKGROUND (UPB)**

\[
\begin{align*}
\text{EDV} & = -7.20 + 0.0641 x \\
\text{ ESV} & = 9.69 \\
\text{ n} & = 23
\end{align*}
\]

**ECHO ENHANCEMENT (MED)**

\[
\begin{align*}
\text{EDV} & = -5.86 + 0.616 x \\
\text{ ESV} & = 9.04 \\
\text{ n} & = 23
\end{align*}
\]

**CONTRAST ECHO ENHANCEMENT (SMB)**

\[
\begin{align*}
\text{EDV} & = -6.78 + 0.541 x \\
\text{ ESV} & = 7.27 \\
\text{ n} & = 23
\end{align*}
\]

**Fig. 3: Relationship between enddiastolic (EDV) and endystolic (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 endystole (table 3).

Discussion

Systematic error: Our results indicate that 2D-echoangiography underestimates angioangiographic volumes significantly (table 1 and fig.3). This seems to be related to the complex geometry of the right ventricle, which consists of three compartments inflow tract, outflow tract and trabeculated portion. 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 carneae, since the muscle bundles are surrounded by the contrast medium. The echocardiographic outline probably represents many in fact the innermost parts of the trabeculations, owing to the finite resolution of the echocardiographic beam. It is limited laterally as well as perpendicular to the scanning plane (10). The outer effect was pointed out by Schnittger et al. (11) for the left ventricle and results in a cavity outline that is inside the angioangiographic 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 angioangiogram and echocardiogram could result in angioangiographic volume, since the flow increases after the injection of angioangiographic contrast medium into the right ventricle. The maximum was observed 2 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 angioangiographic volume was significantly (p < 0.01) less in endystole than in endystole, the mean ratio echo/angio volume being 28% higher in endystole. 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 angioangiographic model volumes. We are the only ones who utilized different factors for endystole and endystole, the latter being approximately 15% smaller than the former (6).

<table>
<thead>
<tr>
<th>a</th>
<th>b</th>
<th>r</th>
<th>sy.x</th>
<th>a</th>
<th>b</th>
<th>r</th>
<th>sy.x</th>
</tr>
</thead>
<tbody>
<tr>
<td>EDV: -5.77</td>
<td>0.849</td>
<td>0.946</td>
<td>9.79</td>
<td>EDV: -5.77</td>
<td>0.849</td>
<td>0.946</td>
<td>9.79</td>
</tr>
<tr>
<td>ESV: -0.84</td>
<td>0.578</td>
<td>0.925</td>
<td>4.95</td>
<td>ESV: -0.84</td>
<td>0.578</td>
<td>0.925</td>
<td>4.95</td>
</tr>
<tr>
<td>SV: -2.89</td>
<td>0.391</td>
<td>0.885</td>
<td>6.97</td>
<td>SV: -2.89</td>
<td>0.391</td>
<td>0.885</td>
<td>6.97</td>
</tr>
<tr>
<td>EF: -0.25</td>
<td>0.458</td>
<td>0.922</td>
<td>7.73</td>
<td>EF: -0.25</td>
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<td>7.73</td>
</tr>
<tr>
<td>ED: 1.36</td>
<td>0.70</td>
<td>0.18</td>
<td>ES: 1.445</td>
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<td>0.18</td>
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<td>0.70</td>
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<tr>
<td>ED-ES = -0.083</td>
<td>0.70</td>
<td>0.18</td>
<td>ES: 1.445</td>
<td>0.70</td>
<td>0.18</td>
<td>ES: 1.445</td>
<td>0.70</td>
</tr>
</tbody>
</table>
| Tab.3: RV shape parameters; PA: Spacial distance pulmonary valve apex-PA; TA: spatial distance tricuspid valve apex-PA; TR: distance tricuspid valve-apex right; Angio: RV angiocardiographic cross-section; MDA: mean diameter equal to the diameter of the sphere with the angioangiographic area-length volume; MIE: mean diameter equal to the diameter of the circle with echocardiographic area.

Echocardiograms: Length TR ED: r = 0.914 v = 30.7% ES: r = 0.786 v = 53.1% Echocardiograms: Area F ED: r = 0.99 v = 18.0% ES: r = 0.995 v = 23.5% Echocardiograms: Area MDA ED: r = 0.946 v = 23.5% ES: r = 0.952 v = 21.6% Tab.4: RV-echocardiogram versus angioangiogram.

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Assessing the shape of the echocardiographic cross-section it appears likely that the enddiastolic/endystolic echocardiographic information differs from the angiographic one. The 2-dimensional ratio length of the cross-section/MDA as shape parameter does not change significantly in enddiastolic and endystolic (table 3). In contrast the angiographic spatial ratio length of the axis tricuspid valve/MDA indicates a less spherical shape in endystole (table 3). Little of the trabeculated portion and more of the inflow/outflow tract is visualized echocardiographically thus preventing quantification 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.

Statistical error: The statistical errors found relating echocardiographic 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 reproducible, 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 2-biplane echocardiographic views (8,13,14) failed. Standardization of these views does not appear possible. The gained information cannot compete with that of standard biplane angiographic 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 values 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 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 in 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 thus awaits further development of echo machines and inadequate 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 end-diastole than in end-systole, 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 Marz-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 delineation. 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.

References:

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