Estimation of pulmonary artery pressure by contrast-enhanced Doppler signals and comparison with catheter-measured pressures

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Determination of pulmonary artery systolic pressure (PASP) is essential for the diagnosis, and the timing and type of management of patients with congenital heart disease (CHD). Usually cardiac catheterization, an expensive and invasive technique, is required for accurate measurement. A number of noninvasive methods for the assessment of PASP have been developed, one of which is estimation of PASP using contrast-enhanced tricuspid regurgitation Doppler signals (TRDS).

In this study, right ventricular systolic pressures (RVSP) and PASP of 36 patients (19 girls, 17 boys; aged 5 months to 15 years) with CHD were estimated by TRDS before and after galactose solution (GS) and were compared with catheterization measurements. Significant TRDS (> 1 m sec.) were obtained in nine of 36 (25%), patients before GS and in 23 of 36 patients (64%) after GS. TRDS were increased significantly by contrast agent. Estimated RVSP and PASP were significantly different from the measured pressures before and after GS. There were significant correlations between the estimated RVSP and PASP and measured RVSP after GS. Estimated pressures were underestimated.

We conclude that it is better to use the estimated PASP on patients with significant TRDS for the classification of PASP.

Key words: contrast enhancement, tricuspid regurgitation, pulmonary artery systolic pressure.

Determination of pulmonary artery systolic pressure (PASP) is essential for the diagnosis, and the timing and type of management of patients with congenital heart disease (CHD)[1]. Usually cardiac catheterization is required for accurate measurement; however, during follow-up, it cannot be used routinely because it is an expensive and invasive technique. A number of noninvasive methods for the assessment of PASP have been developed[2-8]. Estimation of the right ventricular systolic pressure (RVSP) and PASP using the tricuspid regurgitation, peak systolic velocity with the Bernoulli equation is widely accepted[4,5]. However, PASP estimation is not possible if the tricuspid regurgitation Doppler Signals (TRDS) are weak, as this situation causes recording problems. Intravenous contrast medium has been used in recent years to enhance TRDS and to obtain a significant velocity envelope used for the estimation of PASP[9-10].

The purpose of this study was to estimate PASP by the contrast-enhanced tricuspid regurgitation in children with CHD, and to determine its correlation with the catheter-measured PASP.

Material and Methods

The study papulation consisted of 36 patients (19 girls and 17 boys; aged 5 months to 15 years, mean 5.2 ± 3.9 years) who were admitted for cardiac catheterization. Cardiac diagnoses of patients were as follows: VSD in 20 patients, VSD + ASD in 2 patients, VSD + PDA in 1 patient, and AVSD in 1 patient. Body weights of patients ranged between 3.5 and 43.0 kg (mean: 17.2 ± 3.9 kg). Written informed consent was obtained from the parents.

Echocardiographic studies were performed by same echocardiographer using the System VS-Vingmed Sound IA 09423 D equipment with

3.5 and 5 MHz transducers. The Doppler flow velocity pattern and simultaneous lead II electrocardiogram were displayed on a monitor and recorded on videotapes and on a strip-chart recorder at a paper speed of 50-100 mm/sec.

Mean and maximum velocities and velocity time integrals (VTI) of tricuspid regurgitant jet and pulmonary artery (PA) systolic flows were obtained using 2D, color-guided continuous wave Doppler echocardiography. The three consecutive best developed spectral displays swere measured, and average values were used in the calculations. TR jet was recorded by placing the transducer at the cardiac apex and obtaining a four-chamber view. The color-guided ultrasound beam was directed through the tricuspid valve and aligned parallel to the high velocity jet between the right ventricle. Pulmonary artery systolic flow Doppler signals were obtained at the parasternal short axis view.

Galactose solution (GS) (13.5 cc solution and 3 g galactose granules, Ekovist-Schering™) was used as a contrast-enhanced medium. Hand agitation was performed for 10 seconds. Milky white solutions were injected rapidly fom the right brachial or the cubital vein via 22 gauge intravenous catheter. Echocardiographic measurements were redone just after the injection. No complication was observed due to the echo-contrast agent.

Cardiac catheterization was performed within one to three days of echocardiographic study. Pulmonary artery blood flow volume was calculated using the Fick method. Pressures were measured by a fluid-filled end-hole 5-7F NIH catheter connected to the pressure transducer (Siemens Record M: 6030253, E 287 E) which was pulled back from the PA to the right atrium.

Calculations

The systolic pressure of the right ventricle and PASP were estimated using the following formulas:

RVSP = 4V2 (peak tricuspid regurgitant jet velocity) + 10 mm Hg (as a constant right atrial mean pressure).

PASP = RVSP-peak pressure gradient across the pulmonary valve[11].

All patients were clinically stable, and none showed overt signs of congestive heart failure dring the study. The use of contrast medium did not cause any complications during the study.

Statistical Analysis

All data is expressed as a mean value ± SD (minimum-maximum) in the text and the Tables. A two-tailed unpaired t-test was used for statistical comparison by SPSS (The Statistical Package for the Social Science Program) and $p < 0.05$ indicated a significant difference between groups.

Results

Tricuspid regurgitant Doppler signals were recorded in 21 of 36 patients (58%) with CHD. However, TRDS were trivial in 12 of 21 patients (33% of 36). Nine of 21 patients (25% of 36) had significant TRDS (> 1 m/sec). TRDS were not detected in 15 of 36 patients (42%). After galactose solution infection, TRDS were detected in 27 of 36 patients (75%). In 23 of 27 patients (64% of 36), contrast-enhanced TRDS (> 1 m/sec) were sufficient to estimate the PASP (Fig. 1).

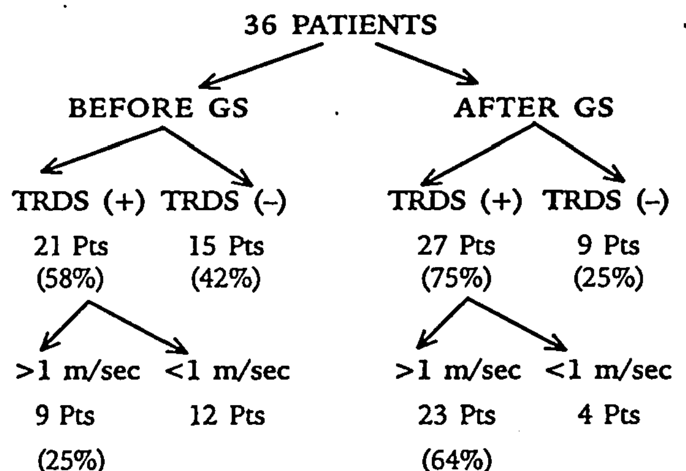

Fig. 1. TRDS positivity before and after galactose solution. TRDS: tricuspid regurgitant Doppler signals; GS: galactose solution.

Tricuspid regurgitant Doppler signals (TRDS) and VTI of TR were enhanced significantly by the GS (Table I). Estimated RVSP and PASP were also significantly increased by the GS (Table I).

Catheter-measured RVSP and PASP of 36 patients are shown in Table II. There were significant differences in the estimated and measured RVSP and PASP before and after GS. There were no significant correlations between the estimated and the measured RVSP and PASP.

After GS, Estimated RVSP and PASP did show significant correlations with the catheter-measured RVSP (r values 0.448 and 0.453,

respectively). Velocities and VTI values of TRDS did show significant positive correlation with the catheter-measured RVSP, before and after GS.

shown in Table III, and all of them increased significantly after GS. After GS, estimated PASP and the RVSP did show significant correlations

Table I. Echocardiographic Measurements of Patients (n = 36)

	Before GS*	After GS*	p
Velocity of TRDS	06525 ± 0.80 (0.00-3.19)	1.9361 ± 1.52 (0.00-131.20)	0.002
VTI of TRDS (cm)	14.36 ± 20.07 (0.00-79.60)	41.82 ± 38.93 (0.00-131.20)	0.006
RVSP (mmHg)	14.19 ± 8.35 (10.00-50.70)	34.02 (10.00-102.16)	0.03
PASP (mmHg)	14.19 ± 8.35 (10.00-50.70)	26.11 ± 19.91 (8.00-84.00)	0.039

*: mean ± SD (min-max).
GS : galactose solution.
TRDS: tricuspid regurgitant Doppler signals.
RVSP : right ventricular systolic pressure.
PASP : pulmonary artery systolic pressure.
VTI : velocity time integrals.

Table II. PA and RV Systolic Pressures of Patients (n=36)

Measurements	Estimated by ECHO*		Catheter*	p
RVSP (mmHg)	Before GS	16.33 ± 9.87 (10.00-50.70)	59.64 ± 27.21 (25.00-119.00)	< 0.0001
	After GS	47.12 ± 24.64 (14.75-102.16)		< 0.0001
PASP (mmHg)	Before GS	16.33 ± 9.87 (10.00-50.70)	46.65 ± 2.82 (19.00-101.00)	< 0.037
	After GS	34.91 ± 20.14 (8.00-84.00)		< 0.038

*: mean ± SD (min-max).
PA : pulmonary artery.
RVSP : right ventricular systolic pressure.
PASP : pulmonary artery systolic pressure.
GS : galactose solution.

The pressure gradient between the right ventricle and pulmonary artery systolic pressure estimated by ECHO and measured by catheterization were as mean ± SD (min-max) 10.90 ± 5.06 mmHg (1.00-19.00 mmHg) and 10.90 ± 7.68 mmHg (0.00-35.00 mmHg). Estimated and measured pressure gardients did not show a significant difference.

Twenty-three patients did show significant increases (0.5 m/sec) in the velocity of TRDS after the GS, and all of them had sufficient velocities of TRDS (> 1 m/sec) for the estimation of RVSP and PASP. Their echocardiographic measurements are

with the catheter-measured RVSP (r values 0.448 and 0.046). There were significant differences in the estimated and measured RVSP and PASP before GS ($p < 0.0001$) (Table IV). Although estimated RVSP and PASP increased significantly after GS, there were significant differences in the estimated and measured RVSP and PASP ($p < 0.038$). There were no significant correlations between the estimated and measured RVSP and PASP before GS the RVSP and PASP estimation by the contrast-enhanced Doppler signals using GS showed significant correlations with the RVSP measurement by cardiac catheterization (r values 0.510 and 0.476, respectively).

Table III. Echocardiographic Measurements of Patients (n = 23)

	Before GS*	After GS*	p
Velocity of TRDS (m/sn)	0.91 ± 0.80 (0.00-3.19)	2.86 ± 1.06 (1.09-4.80)	< 0.0001
VTI of TRDS (cm)	20.01 ± 22.94 (0.00-79.60)	63.09 ± 32.71 (13.68-131.20)	< 0.0001
RVSP (mmHg)	16.33 ± 9.87 (10.00-50.70)	47.12 ± 24.64 (14.75-102.16)	< 0.0001
PASP (mmHg)	16.33 ± 9.87 (10.00-50.70)	34.91 ± 20.14 (8.00-84.00)	< 0.0001

*: mean ± SD (min-max).
GS : galactose solution.
TRDS: tricuspid regurgitant Doppler signals.
RVSP : right ventricular systolic pressure.
PASP : pulmonary artery systolic pressure.
VTI : velocity time integrals.

Table IV. RVSP and PASP of Patients (n=23)

Measurements	Estimated by ECHO*		Catheter*	p
RVSP (mmHg)	Before GS	14.19 ± 8.35 (10.00-50.70)	55.75 ± 24.66 (25.00-119.00)	< 0.0001
	After GS	34.02 ± 26.35 (10.00-102.16)		< 0.0001
PASP (mmHg)	Before GS	14.19 ± 8.35 (10.00-50.70)	45.88 ± 21.04 (19.00-101.00)	< 0.0001
	After GS	26.11 ± 19.91 (8.00-84.00)		< 0.0001

*: mean ± SD (min-max).
RVSP : right ventricular systolic pressure.
PASP : pulmonary artery systolic pressure.
GS : galactose solution.

In general, PASP and RVSP estimated by the contrast-enhanced Doppler signals were underestimated when compared with cardiac catheterization data. The repeatability of the estimated and measured RVSP and PASP were 0.4269 (43%) and 0.4094 (41%), respectively.

Discussion

Contrast echocardiography is used for the detection of valve insufficiencies, intracardiac shunts and flow dynamics[9,10,12,13]. Using the contrast medium, trivial valve regurgitations can be enhanced to obtain the optimum levels for the calculations[14]. Contrast agents are used usually in adults for visulization of the myocardium of the left ventricle[15]. There are several reports about contrast echocardiography in children[16].

In this study, galactose solution was used as a contrast agent in children with CHD. TR in 21 of 36 patients with CHD was detected. However, 12 o 21 patients had trivial TR, and only nine of 36 patients had TR higher than 1 m/sec. With the GS injection, sufficient TR for the estimation of RVSP and PASP could be obtained in 23 of the 36 patients. The GS injection enhanced the TRDS significantly.

It is well known that regurgitant jet Doppler signals are detected in healthy children[17,19]. There are some criteria, such as the time, the duration and the velocity of regurgitation for the definition. Therefore, VTI along with the peak velocity of TR were used for the comparison. Although a correlation of VTI of TR and estimated PASP was found, there was no correlation with the measured PASP.

Sufficient TRDS for the estimation of RVSP and PASP were obtained in 23 of 36 patients with the GS injection. Their estimated values were increased and close to the measured values, but were still significantly different.

The result of the studies about estimation of PASP and RVSP using contrast-enhanced Doppler echocardiography in children and adults showed significant correlations between the estimated and measured pressures. Differences in the results of this study with these other studies may be due to the contrast agent we used[19-20]. Tokushima et al.[20] and Ishii et al.[16] concluded that sonicated albumin was superior to hand-agitated 5% glucose as an enhancer of Doppler signals from the view of a fine, clear demonstration of the velocity envelope of tricuspid regurgitation[16,20]. Galactose solution microbubles were larger than the albumin, so we could not obtain a fine spectral display.

Another important point of argument is right atrial pressure. Multiple approaches for estimating the right atrial pressure have been proposed. They include a clinical evaluation of the jugular venous pulse[12], inferior vena collapsibility index[20], or a constant[21]. We added 10 mmHg to all patients' values as the right atrial pressure. In general, catheter-measured right atrial pressures were under this value in our study. Also, right atrial pressure will increase in the presence of right ventricular dysfunction or dilated right or left heart. The other limitation is detecting the accurate TRDs because of individual sensitivity problems due to the patient and imaging device. These factors could affect the relation between the estimated and measured pressures. In this study, significant enhancement of Doppler imaging by contrast medium, leading to increased sensitivity for flow detection and therefore increased areas of Doppler flow display, were obtained. However, we could not show correlation between the estimated and measured PASP. Our estimated pressures were underestimated as in other studies[20-21]. These results emphasize a basic relation between TRDS and RVSP and PASP, but sohuld not be accepted as a reliable method in the decision making process for heart surgery without cardiac catheterization. It is better to use the estimated PASP by contrast-enhanced agent in patients with significant TRDS for the classification of PASP.

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