Echocardiographic Assessment of the Pulmonary Venous Flow. An Indicator of Increased Pulmonary Flow in Congenital Cardiac Malformations

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Objective *- To identify the left inferior pulmonary vein as an indirect marker of increased pulmonary flow in congenital heart diseases.*

Methods *- We carried out a prospective consecutive study on 40 patients divided into 2 groups as follows: G1 - 20 patients diagnosed with congenital heart disease and increased pulmonary flow; G2 (control group) - 20 patients who were either healthy or had congenital heart disease with decreased or normal pulmonary flow. We obtained the velocity-time integral of the left inferior pulmonary vein flow, excluding the "reverse A" wave, with pulsed Doppler echocardiography.*

Results *- In G1, 19 out of the 20 patients had well-identified dilation of the left inferior pulmonary vein. No G2 patient had dilation of the left inferior pulmonary vein. Dilation of the left inferior pulmonary vein in conditions of increased pulmonary flow had sensitivity of 95%, specificity of 100%, positive predictive value of 100%, and negative predictive value of 95% (1 false-negative case). The integral of time and velocity of the pulmonary venous flow obtained with pulsed Doppler echocardiography was greater in the G1 patients (G1=25.0±4.6 cm versus G2=14.8±2.1 cm, p=0.0001).*

Conclusion *- The identification of dilation of the left inferior pulmonary vein suggests the presence of congenital heart disease with increased pulmonary flow. This may be used as an indirect sign of increased flow, mainly in malformations of difficult diagnosis, such as atrial septal defects of the venous sinus or coronary sinus type.*

Keywords: echocardiography, pulmonary veins, congenital heart diseases

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Echocardiography is currently the method of choice to diagnose congenital cardiac malformations. The 2-dimensional analysis allows both an accurate determination of the defect and identification of the hemodynamic repercussion, ie, hypertrophy or dilation of the cardiac chambers due to the pathophysiological mechanism of the malformation. In the malformations that increase pulmonary flow, we observe dilation of the recipient chambers, either the left ones in posttricuspid malformations, or the right ones in pretricuspid malformations [1]. Doppler assessment of the pulmonary venous flow (return flow of the increased pulmonary flow) has not been used as a parameter to indicate the presence of the defect.

Several studies [2-5] have been carried out, initially in adults and later in children, assessing the pulmonary venous flow in the right superior pulmonary vein because of the easy obtainment of that flow. We have observed that, in conditions of increased pulmonary flow, the left inferior pulmonary vein is extremely dilated, and this could be used as an indirect parameter to assess the presence of cardiac malformations leading to increased pulmonary flow.

The objective of our study was to identify the left inferior pulmonary venous flow in conditions of increased pulmonary flow and to compare these findings with those obtained in healthy children or in children with a cardiac malformation of the normal or decreased pulmonary flow type.

Methods

We consecutively and prospectively studied 40 patients divided into 2 groups as follows: (G1 - group 1) 20 patients with congenital cardiac malformation with increased pulmonary flow, and (G2 - the control group) 20 patients with normal intracardiac anatomy or with other types of malformations (tab I). The patients were not paired by sex or age. The conventional transthoracic echocardiographic study was performed with commercially available equipment (Apogee CX, ATL) and 2.5- and 5.0-MHz transducers and consisted of the sequential 2-dimensional analysis of the cardiac structures and also flow analysis with pulsed Doppler and color-flow mapping. Special attention was given to the identification of the left inferior pulmonary vein, which is better visualized in the apical 4-chamber view, slightly shifted backwards and with a mild counterclockwise rotation. The flow was analyzed with color-flow mapping and pulsed Doppler echocardiography in all participants, and the velocity-time integral of the pulmonary venous flow was calculated in centimeters, excluding the atrial contraction ("reverse A") wave. The Nyquist limit velocity standardized at the beginning of the study was 61 cm/s, and the filter of the device was defined as 400 MHz for pulsed Doppler echocardiography.

The nonpaired Student *t* test was used to compare the ages of the patients, and the nonparametric Mann-Whitney test was used to compare the velocity-time integral of the pulmonary venous flow between the groups. The results obtained in G1 (integral of time and velocity of the total pulmonary venous flow) were also compared with values previously established in the literature [5]. These values were the mean values of the sum of the integrals of time and velocity of the systolic and diastolic flows obtained in the right superior pulmonary vein in children of the same age. Data were, therefore, paired by age. The diagnostic indices of sensitivity (S), specificity (E), positive predictive value (PPV), and negative predictive value (NPV) were also calculated for the identification of the pulmonary venous flow with color-flow mapping according to the following formulae: S = (TP/TP + FN) x 100; E=(TN/TN+FP) x 100; PPV=(TP/TP+FP) x 100; NPV=(TN/TN+FN) x 100; where: TP = true positive, TN = true negative, FP = false positive, and FN = false negative.

Results

The characteristics of the G1 and G2 patients are shown in table I. In regard to the patients' ages, no statistically significant difference was observed (p=0.9). In all patients, most pulmonary veins were identified after a thorough analysis in the apical 4-chamber view; the right inferior pulmonary vein was not visualized in any patient. Dilation of the left inferior pulmonary vein, however, was only identified in patients with increased pulmonary flow.

In G1, the left inferior pulmonary vein was easily identified in 19 out of the 20 patients. It was a dilated structure in the vertical position, parallel to the left posterolateral wall of the left atrium, both on 2-dimensional imaging and on color-flow mapping, a blue laminar structure on the latter. Signs of increased pulmonary flow were evidenced (figs. 1, 2). Pulsed Doppler echocardiography showed a negative deflection, which moves away from the transducer in the inferior-superior direction, with an almost continuous inscription of systolic and diastolic waves. No clear separation between these waves or return to the basal line of the tracing could be seen (fig. 3). The mean of the velocity-time integral in G1 was 25.0±4.6 cm (tab. I). One patient with minimum atrial septal defect and no hemodynamic repercussion had no dilation of that structure (patient 16).

In G2 patients, no dilation of the left inferior pulmonary vein was visualized. Color-flow mapping helped in identifying the pulmonary vein in 6 patients in that group, all of whom were less than 1 year-old, and, for this, a reduction in the Nyquist limit velocity to 44 cm/s was required, because

Table I - Characteristics of the patients studied divided into groups according to age and diagnosis of congenital cardiac malformation. Note the individual data of the integrals of time and velocity of the pulmonary venous flow.

	Increased pulmonary flow (G1)			Normal pulmonary flow (G2)		
Pac.	Age	Malformation	ITV (cm)	Age	Malformation	ITV (cm)
01	1y6m	VSD	26	11m	Nl	14
02	5m	VSD + ASD	36	4y	Mitral reflow	-
03	4m	TGA + VSD	23	9m	Nl	14
04	9m	AVSD + PDA	20	16y	Mitral reflow	-
05	8m	VSD + POF	28	8m	Nl	14
06	5m	PDA + ASD	24	6m	Nl	17
07	1y4m	PDA + ASD	23	7m	Nl	-
08	1y4m	VSD	20	12y	Nl	-
09	16y	PDA	24	6m	Nl	11
10	2y	VSD	20	6m	Nl	13
11	6m	AVSD	28	2y	Nl	-
12	6m	AVSD	22	1y	Nl	15
13	22y	PDA	21	9m	Nl	14
14	9y	AVSD	33	2y3m	Nl	-
15	9m	Tr. Art.I	26	9m	Nl	15
16	4y	ASD	18	8m	Nl	15
17	2y	ASD + VSD	26	14y	MVP, no reflow	-
18	1y	VSD	31	1y4m	Nl	-
19	9m	VSD + POF	24	1y	Nl	19
20	11m	ASD	27	10m	Nl	17

ITV - velocity-time integral of the total pulmonary venous flow obtained with pulsed Doppler echocardiography. ASD - atrial septal defect; VSD - ventricular septal defect; PDA - persistent ductus arteriosus; TGA - transposition of the great arteries; AVSD - total atrioventricular septal defect; POF - patent oval foramen; Tr. Art. I - type I truncus arteriosus; Nl- normal; MVP - mitral valve prolapse; Dash corresponds to the absence of data about a certain parameter. Age: p = 0.9; ITV: p = 0.0001.

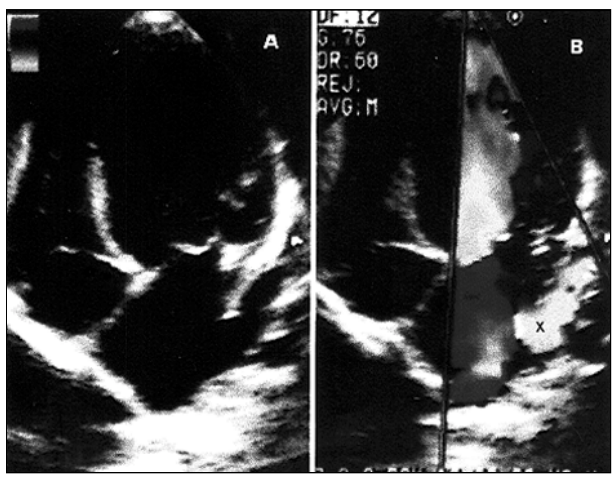

Fig. 1 - Two-dimensional echocardiographic data obtained in apical 4-chamber view: A) dilated left inferior pulmonary vein visualized close to the left atrial appendage; B) color-flow mapping showing laminar flow inside the left inferior pulmonary vein (x) draining into the left atrium.

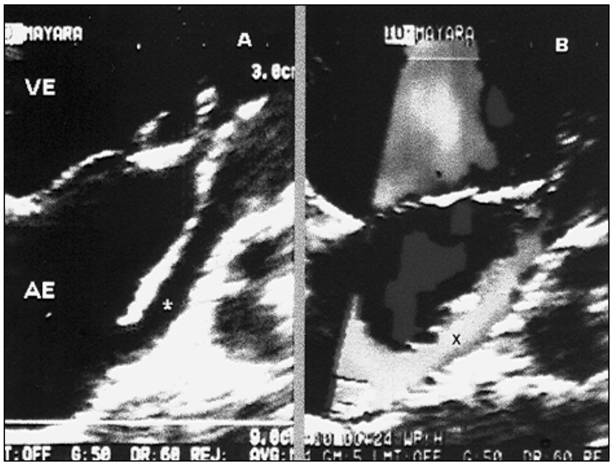

Fig. 2 – Magnification of the 2-dimensional echocardiographic data obtained on apical 4-chamber view: A) left inferior pulmonary vein (*) connected to the left atrium; B) color-flow mapping showing a laminar flow draining into the left atrium.

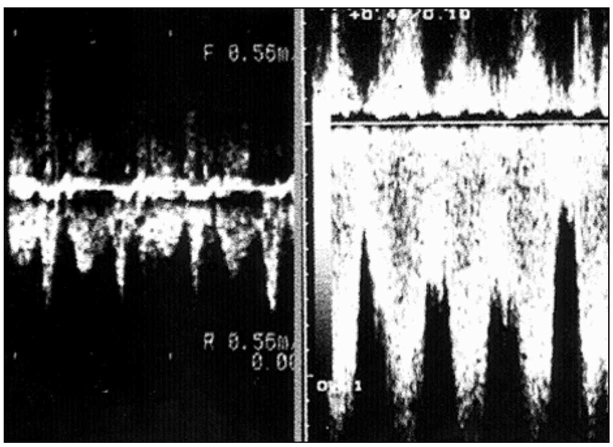

Fig. 3 - Echocardiographic data of the pulsed Doppler assessment: A) flow obtained in a healthy subject showing signs of low amplitude with good definition of the systolic and diastolic flows; B) flow obtained in a patient with persistent ductus arteriosus and atrial septal defect (patient 6) showing a continuous high-velocity flow.

identification with the previously established Nyquist velocity was not possible. The mean of the velocity-time integral obtained with pulsed Doppler echocardiography in G2 was 14.8±2.1 cm, and the comparison between the 2 groups showed a statistically significant difference (p=0.0 001). In all G2 patients in whom left inferior pulmonary venous flow was identified, the Doppler echocardiography showed inscription of the systolic and diastolic deflections, whose separation was easily identified. Addition of the velocity-time integral of both deflections was performed. In 8 G2 patients, the pulmonary venous flow could not be obtained using Doppler echocardiography. The mean of the addition of the integrals of time and velocity of the systolic and diastolic deflections of the pre-established values in the literature [5] was 18.8±4.2 cm. The comparison of the individual data for age with the velocity-time integral in G1 showed a statistically significant difference (p=0.0004).

The diagnostic indices to identify the pulmonary venous flow with color-flow mapping with the previously established Nyquist velocity showed sensitivity of 95%, specificity of 100%, positive predictive value of 100%, and negative predictive value of 95%.

Discussion

The analysis of the hemodynamic repercussion of congenital cardiac malformations with increased pulmonary flow is easily performed with 2-dimensional echocardiography, through visualization of dilation of the cardiac chambers that receive the increased pulmonary flow. This dilation correlates strictly with the degree of the increase in the pulmonary flow and the site of the defect. Therefore, pretricuspid malformations dilate the right cardiac chambers and posttricuspid lesions dilate the left cardiac chambers [1]. The pulmonary venous return has received little attention. Pickoff et al [6], in a study with pulsed Doppler echocardiography, reported that it was easier to obtain signals of flow inside the left atrium in situations of increased pulmonary flow, suggesting that this could be due to the dilation of the pulmonary veins or to a greater flow velocity, both resulting from an increase in the pulmonary flow. That study differs from the one by Smallhorn et al [2], who analyzed the right superior pulmonary venous flow and observed no difference between situations of normal, increased, or reduced pulmonary flow, and the postoperative period of different types of cavopulmonary anastomosis.

During a short period of time, we observed that, in situations of increased pulmonary flow, the inferior pulmonary vein is dilated and easily visualized on transthoracic echocardiography. In the apical 4-chamber view, that structure is seen in the vertical position and parallel to the left atrial posterolateral wall, slightly shifted backwards and with a mild counterclockwise rotation. This has not been previously reported in the literature. In our study, we found a very high frequency of dilation of the left inferior pulmonary vein in situations of increased pulmonary flow as compared with situations of normal pulmonary flow, in which no case of dilation of the left inferior pulmonary vein was observed. In the patients with normal or decreased pulmonary flow, most pulmonary veins were identified in the posterior region of the left atrium, in their usual location [7], the right inferior pulmonary vein being the most difficult to be located. The left inferior pulmonary vein was always identified in the left atrial posterolateral region, close to the left atrial appendage, as a blue flow on the color-flow mapping, as had been previously reported in the literature [2]. Even though a red flow corresponding to the right superior pulmonary vein was identified inside the left atrium on color-flow mapping, this vein was not analyzed because its trajectory was not clearly visualized. In addition, the right superior pulmonary vein flow acquires a sprayed appearance in situations of increased flow, and the recording obtained on pulsed Doppler echocardiography varies depending on the position of the volume sample. The Doppler study showed an almost continuous flow between the systolic and diastolic deflections of the pulmonary flow in G1 patients, probably due to the presence of anterograde flow during the entire cardiac cycle resulting from the increased pulmonary flow. This was previously reported by Agata et al [8] in a study with pulsed Doppler in newborn infants. Those authors observed in the first hour of life an almost continuous pulmonary venous flow of higher velocity, similar to that obtained in situations of congenital obstruction of the pulmonary veins, and compared it with the flow obtained 24 hours later, which was intermittent and with a lower velocity, similar to the flow in adults. The authors suggested that this difference might be due to the increased pulmonary flow in the first hours of life resulting from persistent ductus arteriosus.

We believe that the high sensitivity and specificity in identifying the left inferior pulmonary vein may serve as a marker of the presence of increased pulmonary flow, and, therefore, may be used as an indirect signal for the diagnosis of its existence. This could be particularly important in cases of malformations of difficult diagnosis, such as atrial septal defects of the venous or coronary sinus type. This may even be useful to assess the repercussion of the dominant lesion in situations accompanied by pulmonary stenosis.

As the pulmonary venous flow reflects directly the degree of flow increase, some studies may be carried out based on this finding, such as the quantification of the degree of flow increase, or even, the performance of tests to assess pulmonary vascular hyperreactivity.

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