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Dynamics of the Pulmonary Venous Flow in the Fetus and Its Association With Vascular Diameter

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Background**—**The usual positioning of the Doppler sample volume to assess fetal pulmonary vein flow is in the distal portion of the vein, where the vessel diameter is maximal. This study was performed to test the association of the pulmonary vein pulsatility index (PVPI) with the vessel diameter.

Methods and Results**—**Twenty-three normal fetuses (mean gestational age, 28.6±5.3 weeks) were studied by Doppler echocardiography. Pulmonary right upper vein flow was assessed adjacent to the venoatrial junction ("distal" position) and in the middle of the vein ("proximal" position). The vessel diameter was measured by 2D echocardiography with power Doppler, and the PVPI was obtained by the ratio (maximal velocity [systolic or diastolic peak]−minimal velocity [presystolic peak])/mean velocity. The statistical analysis used *t* test and exponential correlation studies. Mean distal diameter was 0.33±0.10 cm (0.11 to 0.57 cm), and mean proximal diameter was 0.16±0.08 cm (0.11 to 0.25 cm) ($P<0.0001$). Mean distal PVPI was 0.84±0.21 (0.59 to 1.38), and mean proximal PVPI was 2.09±0.59 (1.23 to 3.11) ($P<0.0001$). Exponential inverse correlation between pulmonary vein diameter and pulsatility index was highly significant ($P<0.0001$), with a determination coefficient of 0.439.

Conclusions**—**In the normal fetus, the pulmonary venous flow pulsatility decreases from the lung to the heart, and this parameter is inversely correlated to the diameter of the pulmonary vein, which increases from its proximal to its distal portion. This study emphasizes the importance of the correct positioning of the Doppler sample volume, adjacent to the venoatrial junction, to assess pulmonary venous flow dynamics. **(*Circulation*. 2003;108:2377-2380.)**

Key Words: fetus ■ echocardiography ■ blood flow ■ physiology ■ vessels

Fetal Doppler echocardiography is an expanding field, and functional studies are now an essential part of the routine examination.

The paramount importance of the events taking place in the left atrium, such as flow through the foramen ovale, coming from the ductus venosus, mitral flow patterns, and flow from the pulmonary veins, are directly related to left atrial pressure and volume and to left ventricular relaxation and compliance. Analysis of the pulmonary vein flow has been used along with other parameters in the assessment of fetal diastolic function.[1,2] The pulmonary vein pulsatility index (PVPI) reflects the relative impedance to the forward flow and is believed to be better comparable than absolute values of individual waveforms and independent of the insonation angle.[3] The standard position of the Doppler sample volume to obtain the pulmonary vein flow is in the distal portion of the vein, adjacent to the venoatrial junction, where the vessel diameter is maximal. Morphometric studies of the pulmonary venous vasculature confirm that the pulmonary veins show a tapering pattern from the left atrium to the hylum,[4,5] and mathematical models show that the flow wave is altered by the change in the cross-sectional area of the vessel.[6–10] It seemed logical to suppose that if the Doppler sampling were performed more proximally, in a region where the pulmonary vein size was smaller, the results could be different, possibly expressing an increased impedance to the forward flow where the vessel was narrower.

Thus, this study was performed to test the hypothesis that the PVPI should be lower in the venoatrial junction than at a more proximal site and that this behavior should be correlated to the progressive decrease in the vessel diameter from the left atrium toward the lung.

Methods

Twenty-three normal fetuses, with a mean gestational age of 28.6±5.3 weeks (20 to 36 weeks) were studied by cross-sectional and Doppler echocardiography. Any maternal or fetal abnormalities excluded the patient from the study. Commercially available equipment with 2D, M-mode, pulsed, and continuous Doppler; color flow mapping; and power angio-Doppler capabilities was used.

Considering the established reproducibility of transthoracic pulmonary venous Doppler flow indices,[11] intraobserver and interobserver variability was not calculated.

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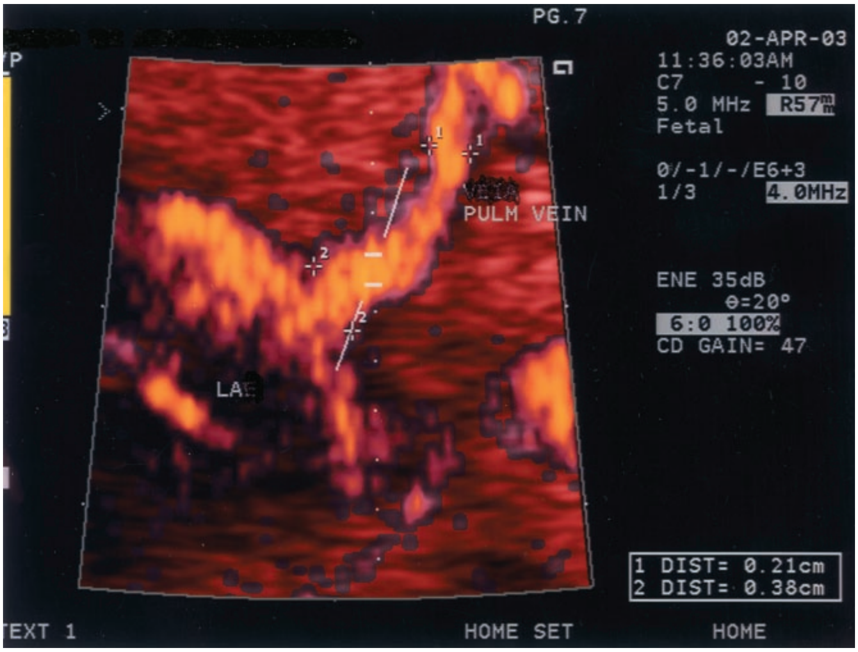

Figure 1. Right upper pulmonary (PULM) vein imaging in a 33-week fetus by 2D echocardiography enhanced by power Doppler. Notice progressive increase of vessel diameter toward left atrium (LA).

Pulmonary venous flow was assessed in the upper right vein at 2 different sites: adjacent to the opening to the left atrium ("distal" position) and in the middle of the vein ("proximal" position), below the level of the middle lobe vein.[12] The vessel diameter was measured at the 2 sites by 2D echocardiography enhanced with power Doppler (Figure 1). PVPI was obtained by the pulsed Doppler ratio, as follows: (maximal velocity [systolic or diastolic peak]−minimal velocity [presystolic peak])/mean velocity, electronically calculated by the equipment after manual tracing of the pulmonary waveforms during the entire cardiac cycle (Figure 2). The mean of 5 measurements was considered, in the absence of fetal breathing movements.

Informed consent was obtained in every case.

Statistical analysis used *t* test and exponential correlation studies, with a confidence limit of 99%.

Results

Mean distal internal diameter was 0.33±0.10 cm (0.11 to 0.57 cm), with a median of 0.32 cm, and mean proximal diameter was 0.16±0.08 cm (0.11 to 0.25 cm), with a median of 0.16 cm ($P<0.0001$) (Figure 3).

There was no statistical difference between mean systolic (S wave) and diastolic (D wave) peak velocities at the 2 sites (distal S=0.20±0.09 m/s [0.17 to 0.58 m/s], proximal S=0.22±0.08 m/s [0.14 to 0.52 m/s]; distal D=0.21±0.09 m/s [0.14 to 0.53 m/s], proximal D=0.19±0.14 m/s [0.10 to 0.53 m/s]).

Mean peak presystolic velocity (A wave) was significantly higher in the distal position (A=0.12±0.04 m/s [0.06 to 0.16 m/s]) than at the proximal site (A=−0.12±0.07 m/s [−0.13 to 0.09 m/s]) ($P=0.002$).

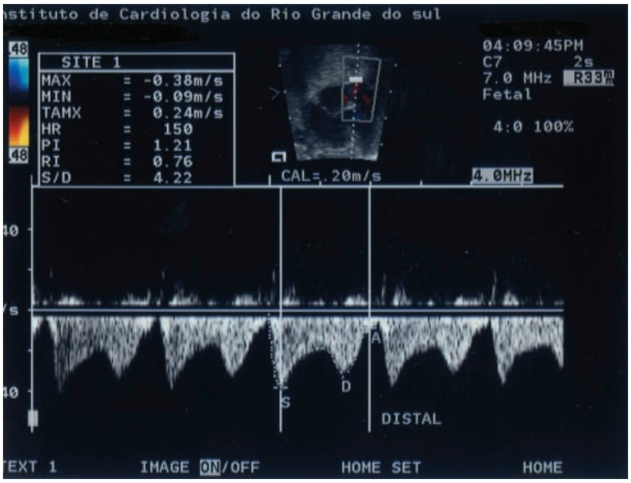

Figure 2. Doppler tracing of a typical distal pulmonary vein flow. Velocities were electronically calculated after manual tracing of waveforms. Presystolic velocity is 0.09 m/s, and calculated pulsatility index is 1.21.

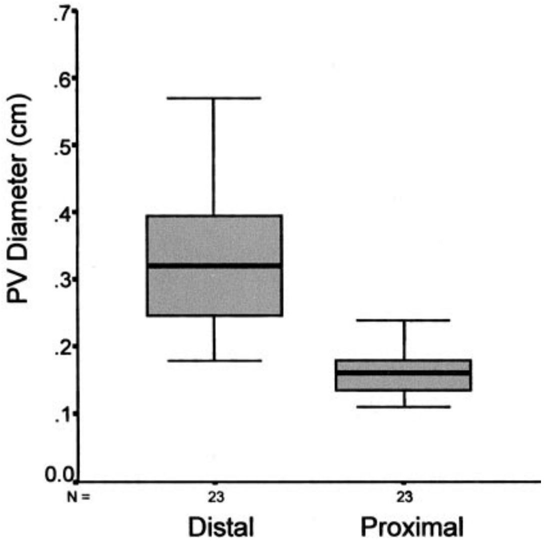

Figure 3. Diagram showing median distal and proximal pulmonary vein (PV) diameters. Horizontal bars above and below median boxes represent maximal and minimal values of PV diameter.

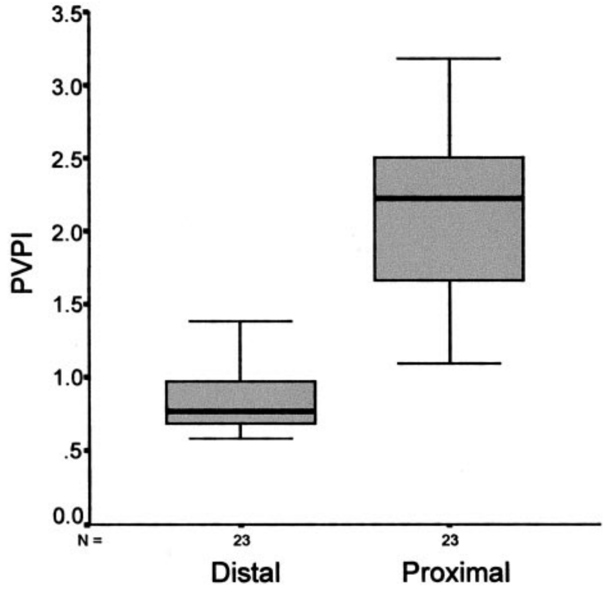

Figure 4. Diagram showing median distal and proximal PVPIs. Horizontal bars above and below median boxes represent maximal and minimal values of PVPI.

Mean distal PVPI was 0.84±0.21 (0.59 to 1.38), with a median of 0.77, and mean proximal PVPI was 2.09±0.59 (1.23 to 3.11), with a median of 2.22 ($P<0.0001$) (Figure 4).

Exponential inverse correlation between pulmonary vein diameter and pulsatility index was highly significant ($P<0.0001$), with a determination coefficient of 0.439 (Figure 5).

Discussion

Studies on human embryonic and fetal lungs demonstrate that the pulmonary arteries form by vasculogenesis,[13] but there is less information on the early development of the pulmonary veins. Studies on maturation of pulmonary venous smooth muscle suggest that a developmentally regulated remodeling of the vein walls may reduce resistance to blood flow in fetal life.[14] It has also been shown that the development of the airways and pulmonary veins occurs at different times and that the branching patterns of these structures are not interdependent.[15–17] The common pulmonary vein develops within the sinus venosus segment[18] and is later incorporated into the morphological left atrium.[19] Morphometric studies in animals[4] and in humans[5] demonstrate that the branching patterns of the pulmonary veins show many orders of tapering, from the left atrium, where the diameter of the vessel (and its cross-sectional area) is maximal, toward the pulmonary bed, where it is minimum.

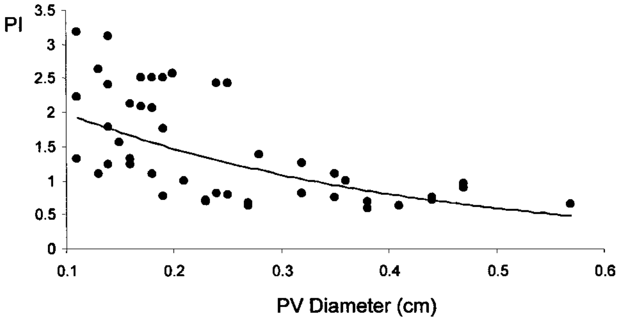

Figure 5. Diagram depicting inverse correlation between PVPI and vessel diameter.

An experimental hemodynamic study showed that the pulmonary vein pressure varied depending on the recording site, resembling pulmonary artery pressure closer to the pulmonary capillary bed and left atrial pressure closer to the venoatrial junction.[20] The same rationale applies when the flow velocities from the lung to the heart are considered, with the pulmonary vein diameter at the different sites probably being the main determinant, as is demonstrated in the present study. Other factors involved have been evaluated, such as left atrium relaxation and compliance and left ventricular function.[21–27] Pulmonary vein relaxation, mediated by C-type natriuretic peptide, is uniform and thus does not allow segmental variations.[28]

The effects of vessel tapering in the pulmonary circulation have been studied by nonlinear models,[6,10] and the role of the vessel cross-sectional area in the flow wave dynamics has also been assessed.[7] A theoretical model designed to evaluate the wave transmission in a stenotic tube suggests that nonsevere stenoses may cause significant wave reflections,[8] which is consistent with the idea that the flow impedance is related to the diameter of the tube.

Because Doppler analysis of the pulmonary venous waveforms is widely used in clinical practice,[1–3,29–35] it is imperative to have the sample volume correctly positioned in the distal portion of the pulmonary vein, near the venoatrial junction, to achieve reliable results, because this fetal study showed that the presystolic velocity decreases and the pulsatility index increases when a more proximal site is sampled.

It has been demonstrated that, in the normal fetus, the pulsatility of the pulmonary vein decreases along the way from the lung to the heart and that this parameter is inversely correlated to the cross-sectional diameter of the pulmonary vein, which increases from the proximal to the distal portion of the vessel.

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