Non-invasive quantitation of cardiac hemodynamics with Echocardiography and Doppler ultrasound
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Gheorghe AM Pop,* Maureen van de Vlugt,* Aline Huizenga*

Summary

Until recently hemodynamic assessment of the heart had to be done invasively by catheterization. Nowadays echocardiography with Doppler has demonstrated to give similar results by a non-invasive approach. The methods to determine several hemodynamic parameters by echocardiography without Doppler are discussed (dimensions of the cavities, left ventricular mass, ejection fraction) as well as with use of Doppler (cardiac output, quantification of valve regurgitation and stenosis, pressure gradients, valve area and intracardiac pressure). Basic formulas such as the continuity and simplified Bernoulli equations are discussed.

Key words: Non-invasive assessment of cardiac hemodynamics. Echocardiography. Doppler.

Palabras clave: Estudio de la hemodinámica cardíaca con métodos no invasivos. Ecocardiografía Doppler.

Introduction

Until recently hemodynamic assessment of the heart could be obtained only by the invasive approach of catheterization. In the last years echocardiography and especially Doppler flow analysis have demonstrated, that this non-invasive method gives almost similar results and sometimes even better.1,2 Echocardiography has the advantages that it can be performed at the bedside, it is a rapid and very safe method and it is relatively inexpensive. Furthermore, it has offered the opportunity to re-evaluate the hemodynamic alterations of the heart as frequent as necessary, which can be used for optimizing medical treatment and establishing the right moment for surgical repair, if necessary.

II M-Mode and 2D evaluation of cardiac hemodynamics (without Doppler)

The evaluation of cardiac hemodynamics by M-Mode and 2D echocardiography without Doppler often gives only indirect evidence of abnormalities. However, the obtained data are especially helpful to determine the duration of an existing defect by showing the presence and intensity of organ damage in the heart (the degree of hypertrophy and/or dilatation). It also often helps to elucidate the etiology of an hemodynamic alteration (presence of wall movement abnormalities, vegetations, myxoma, etc.). In Table I a summary is made of the several M-Mode and 2D findings and the corresponding hemodynamic alterations.

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Left ventricular ejection fraction (LVEF)
Several large clinical trials in heart failure patients have shown the strong predictive power of the LVEF to predict major cardiovascular events. Therefore, determination of LVEF has become the most utilized tool in both research and clinical practice to express left ventricular (LV) contractile performance. LVEF by contrast ventriculography and radionuclide ventriculography are considered as ‘gold standards’. However, the resolution of 2-D transthoracic echocardiography (especially when ‘harmonics’ and/or contrast agents are added) has improved in recent years and several studies have demonstrated an excellent correlation with the ‘gold standard’. The American Society of Echocardiography recommends to determine LVEF by computing systolic and diastolic volumes from biplane planimetry of paired orthogonal long axis views. Another established method to evaluate ventricular systolic function is the wall motion scoring (WMI). WMI is a mean score of wall motion derived from values of regional wall motion assigned in a segmental LV model. Preferentially, 16 segments are used and scored in all standard 2-D views. A linear relationship appears to exist between WMI and LVEF; hence, a regression equation may be used to convert WMI to LVEF.

Estimation of Stroke Volume and Cardiac Output
The flow through a certain cross-sectional area (CSA) can be calculated by the formula:
Flow rate = CSA x Flow velocity

Cardiac output is calculated by multiplying SV with the heart frequency.

IV Quantitation of heart valve defects
A Valve regurgitation volume
Two methods exist to estimate the regurgitant volume by Echo/Doppler: the volumetric method and the proximal isovelocity surface area (PISA) method. In the volumetric method, the regurgitant volume is the difference between the total forward stroke (Q_total) and the systemic stroke volume (Q_systolic), hence regurgitant volume = Q_total - Q_systolic. For example calculation of a mitral insufficiency needs determination of Q_total through the CSA at the mitral orifice and determination of the Q through the CSA at the LVOT. On the other hand, for calculation of an aortic insufficiency the mitral inflow (Q_inflow) must be subtracted from the total flow (Q_total) at the LVOT level.

Table I. Summary of several M-mode and 2-D echo findings and their corresponding hemodynamic alterations.

<table>
<thead>
<tr>
<th>M-Mode and 2 D findings</th>
<th>Hemodynamic alterations</th>
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<tbody>
<tr>
<td>Left ventricular hypertrophy</td>
<td>Long-lasting hypertension or AS</td>
</tr>
<tr>
<td>Diminished fractional shortening</td>
<td>Decreased contraction force</td>
</tr>
<tr>
<td>Fluttering of mitral valve</td>
<td>Aortic regurgitation</td>
</tr>
<tr>
<td>Systolic anterior motion of mitral valve</td>
<td>Dynamic obstruction of LVOT</td>
</tr>
<tr>
<td>Midsystolic pulmonary valve closure</td>
<td>Dynamic obstruction of LVOT</td>
</tr>
<tr>
<td>Dilated RV + D-shaped LV</td>
<td>Pulmonary hypertension</td>
</tr>
<tr>
<td>Dilated IVC with lack of inspiratory collapse</td>
<td>Increased RV systolic pressure</td>
</tr>
<tr>
<td>Persistent bowing of atrial septum to RA or LA</td>
<td>Increased LA or RA pressure</td>
</tr>
<tr>
<td>Diastolic RA and RV wall inversion or collapse</td>
<td>Cardiac tamponade</td>
</tr>
<tr>
<td>Abnormal ventricular septal motion</td>
<td>Constrictive pericarditis</td>
</tr>
<tr>
<td>Abnormal TAPSE</td>
<td>RV dysfunction</td>
</tr>
</tbody>
</table>

RV= right ventricle; LV= left ventricle; RA= right atrium; LA= left atrium; LVOT= left ventricular outflow tract; IVC= inferior vena cava; AS= aortic stenosis; TAPSE = Tricuspid Annulus Plane Systolic Excursion
The PISA method is based on the continuity equation and the concept of conservation of flow. The regurgitant jet is calculated by determining the effective regurgitant orifice area (ERO), because the regurgitant volume = ERO x regurgitant TVI. Using the Nyquist limit of the color-coded Doppler signal, the flow velocity proximal to the regurgitant orifice (Alias V) can be determined (Fig. 1). The area of the isovelocity hemisphere is calculated as $2\pi r^2$; subsequently, flow rate = $2\pi r^2 \times$ Alias V = ERO x regurgitant velocity. Finally, the regurgitant volume can be determined, because this is equal to the regurgitant orifice area (ERO) multiplied by the mitral regurgitation TVI.

**B Valve pressure gradient** The blood velocities can be converted to pressure gradients using the simplified Bernoulli equation. The complete Bernoulli equation has 3 components (convective acceleration, flow acceleration and the viscous friction), but for the measurement of the flow gradient across a narrowed orifice in the clinical setting only the factor of convective acceleration is important. Hence, 

**Pressure gradient** $(\Delta P) = 4 \times (\text{Peak flow velocity})^2$

The measured peak flow velocity is an instantaneous event, so the converted pressure gradients will also be instantaneous and represent maximal values. The peak-to-peak gradient as measured in aortic stenosis during catheterization is not instantaneous and is obtained from the difference between maximal pressure in the left ventricle versus maximal pressure in the aorta, both of which do not occur at the same moment. Hence, the maximal calculated pressure gradient by Doppler technique will always be higher than the peak-to-peak gradient during catheterization. Several studies have demonstrated an excellent correlation between the pressure data calculated by Doppler and the intracavitary pressure measurements by cardiac catheterization.

**C Valve area calculation** For calculation of the valve area the continuity equation can be used (Fig. 2). As one of the areas (A1) can be measured, and the 2 velocities before and after the stenotic or regurgitant area can be determined, the area of interest (A2) can be calculated. For example in aortic stenosis the A1 will be the diameter of the left ventricle outflow tract, the V1 is the flow velocity in the LVOT and the V2 is the flow velocity after the aortic valve area. Another method to estimate the severity of the valve area is determination of the pressure half time (PHT)(10). The PHT is the time interval for the peak pressure gradient to reach its half level. As the pressure gradient is calculated by the

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**Fig. 1.** From the velocity at which aliasing occurs ($V_a$) and the radius of the isovelocity hemisphere (A) the regurgitant volume can be calculated using the formulas depicted in B.

**Fig. 2.** Schematic description of the continuity equation.
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Evolution of the size of cardiac ultrasound imaging equipment.

Fig. 3. Evolution of the size of cardiac ultrasound imaging equipment.

The pressure drop across a valve, which finding can be used to calculate the pressure in the different cardiac cavities. For example: from the tricuspid regurgitant jet velocity the RV pressure can be estimated (according to the simplified Bernoulli equation) by adding (TR velocity)² x 4 to the RA pressure, which usually is 10 mm Hg. In a similar way the end diastolic LV pressure (LVEDP) can be calculated, if an aortic regurgitation (AR) can be detected: \( LVEDP = DBP - (AR\ EVD)^2 \times 4 \) in which DBP is systemic diastolic blood pressure. Another way to estimate LVEDP is to consider the pattern of the pulmonary venous flow and the mitral inflow. Finally, even the typical contractility parameter of dp/dt, which is normally derived from invasive measurements, can be estimated by Doppler flow analysis.

VI Conclusion
Non-invasive quantitation of hemodynamic parameters by echocardiography with Doppler has become a reliable tool in clinical research and for clinical decision making in daily practice. As echo/Doppler equipment is becoming smaller and more portable, in time the echocardiograph may become a modern replacement for our present stethoscope (Fig. 3).

References

11. SOHN DW, CHOI YJ, ON BH, LEE MM, LEE YW: Estimation of left ventricular end-diastolic pressure with the difference in pulmonary venous and mitral A durations is limited when mitral E and A waves are overlapped. J Am Soc Echocardiogr 1999; 12(2): 106-112.