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Artículo:

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Non-invasive quantitation of cardiac hemodynamics with Echocardiography and Doppler ultrasound

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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 Bernouilli equations are discussed.

Resumen

VALORACIÓN DE LA HEMODINÁMICA CARDÍACA CON MÉTODOS NO INVASIVOS: ECOCARDIOGRAFÍA Y ULTRASONIDO DOPPLER

Hasta hace poco, la valoración hemodinámica del corazón empleaba al cateterismo (técnica invasiva) como herramienta. Actualmente, la ecocardiografía con Doppler ha mostrado resultados similares. En este trabajo, se discuten los métodos ecocardiográficos sin Doppler para evaluar varios parámetros hemodinámicos (dimensiones de las cavidades, masa del ventrículo izquierdo, fracción de eyección), así como con el uso de Doppler (gasto cardíaco, cuantificación de regurgitación y estenosis valvulares, gradientes de presión, área valvular y presión intracardíaca). Adicionalmente, se discuten las ecuaciones de continuidad y la de Bernoulli simplificada.

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

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

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

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'.[3] The American Society of Echocardiography recommends to determine LVEF by computing systolic and diastolic volumes from biplane planimetry of paired orthogonal long axis apical views.[4] The most recommended algorithm for use in clinical practice is Simpson's rule, also known as the 'disc summation method'. Another established method to evaluate ventricular systolic function is the wall motion scoring (WMI).[5] 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.

III 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

The cardiac flow is pulsatile during a cardiac cycle and a sum must be made of all velocities within one cycle; this sum is called time velocity integral (TVI).[6] By tracing the Doppler velocity signal TVI can be determined and normally this calculation is done automatically by the newest Echo/Doppler units. Subsequently, stroke volume (SV) is calculated by multiplying TVI by CSA.

SV= CSA x TVI

The CSA for calculation of SV is determined at the LVOT just beneath the aortic cusps in the parasternal long axis view. It is considered to be circular, so it can be determined by measurement of the orifice diameter (D):

$$CSA = (D/2)^2 \times \pi = D^2 \times 0.785 \text{ or } SV = D^2 \times 0.785 \times TVI$$

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[6] the regurgitant volume is the difference between the total forward stroke (= Q_{total}) and the systemic stroke volume (= Q_s), hence regurgitant volume = Q_{total} - Q_s. For example calculation of a mitral insufficiency needs determination of Q_{total} through the CSA at the mitral orifice and determination of the Q_s through the CSA at the LVOT. On the other hand, for calculation of an aortic insufficiency the mitral inflow (= Q_s) must be subtracted from the total flow (Q_{total}) at the LVOT level.

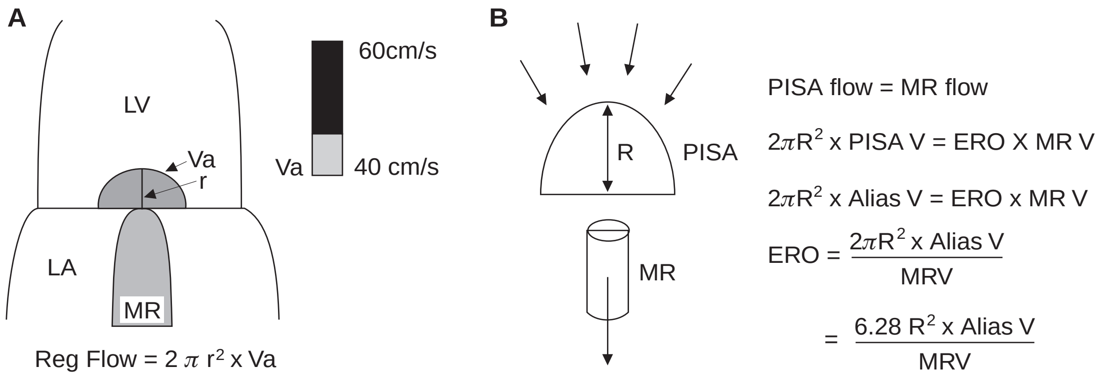

Fig. 1. From the velocity at which aliasing occurs (V_a) and the radius of the isovelocity hemisphere (A) the regurgitant volume can be calculated using the formulas depicted in B.

The PISA method is based on the continuity equation and the concept of conservation of flow.[7] 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 2π x r^2; subsequently flow rate = 2π x r^2 x 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,

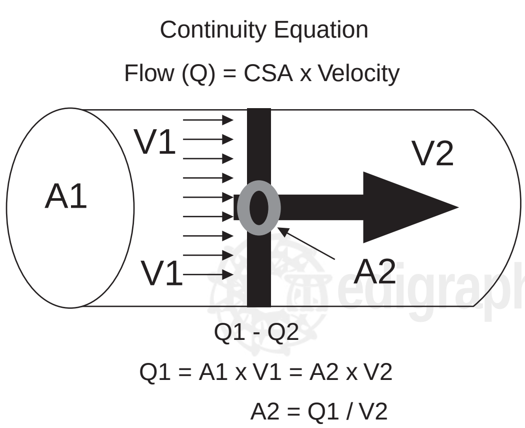

Fig. 2. Schematic description of the continuity equation.

Pressure gradient (ΔP) = 4 x (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.[8,9]

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

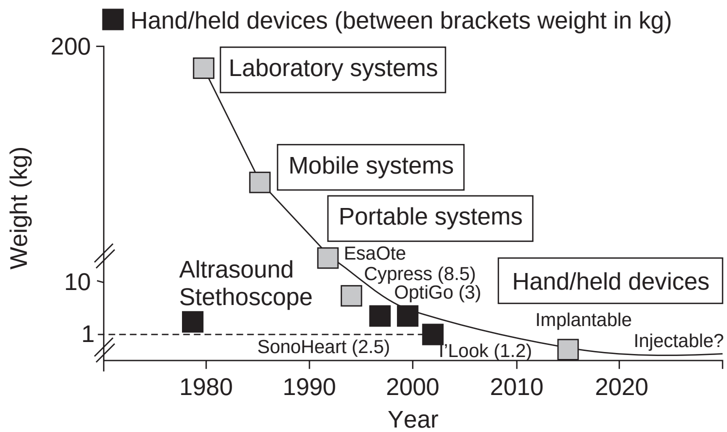

Fig. 3. Evolution of the size of cardiac ultrasound imaging equipment.

square root of the flow velocity, this PHT is the same as the time interval of the peak velocity to reach v2 x the level of the peak velocity.

The deceleration time (DT) is the time interval from the peak velocity to when it reaches zero baseline and the DT is always proportionally related to the PHT, according to PHT= 0.29 x DT.

V Intracardiac pressures The velocity of a regurgitant jet is related to 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:[8] ***$LVEDP = DBP - (AR\ EDV)^2 \times 4$*** 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.[11] Finally, even the typical contractility parameter of dp/dt, which is normally derived from invasive measurements, can be estimated by Doppler flow analysis.[12]

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)*.[13]

References

1. FEIGENBAUM H: *Evolution of echocardiography*. Circulation 1996; 93: 1321-1327.
2. TEIRSTEIN PS, YOCK PG, POPP RL: *The accuracy of Doppler ultrasound measurement of pressure gradients across irregular, dual, and tunnel-like obstructions to blood flow*. Circulation 1985; 72: 577-584.
3. MCGOWAN JH, CLELAND GF: *Reliability of reporting left ventricular systolic function by echocardiography: a systematic review of 3 methods*. Am Heart J 2003; 146: 388-397.
4. SCHILLER NB, SHAH PM, CRAWFORD M: *Recommendations for quantitation of the left ventricle by two-dimensional echocardiography: American Society of Echocardiography Committee on Standards, Subcommittee on Quantitation of Two-Dimensional Echocardiograms*. J Am Soc Echocardiogr 1989; 2: 358-367.
5. EDWARDS WD, TAJIK A, SEWARD JB: *Standardized nomenclature and anatomical basis for regional tomographic analysis of the heart*. Mayo Clin Proc 1981; 56: 479-497.
6. OH JK, SEWARD JB, TAJIK AJ: *The Echo Manual. Second Edition* 1999; Chapter 6: 59-71.
7. MESSIKA-ZEITOUN D, FUNG YIU S, CORMIER B, IUNG B, SCOTT C, VAHANIAN A, TAJIK AJ, ENRIQUEZ-SARANO M: *Sequential assessment of mitral valve area during diastole using colour M-mode flow convergence analysis: new insights into mitral stenosis*. Eur Heart J 2003; 24: 1244-1253.
8. NEUMANN A, SOBLES JS, ANAGNOS PC, KAGZI M, PARRILLO JE: *Accurate noninvasive estimation of left ventricular end-diastolic pressure: comparison with catheterization*. J Am Soc Echocardiogr 1998;11(2): 126-131.
9. DABAGHI SF, ROKEY R, RIVERA JM, SALIBA WI, MAJID PA: *Comparison of echocardiographic assessment of cardiac hemodynamics in the intensive care unit with right-sided cardiac catheterization*. Am J Cardiol 1995; 76(5): 392-395.
10. THOMAS JD, WEYMAN AE: *Doppler mitral pressure half-time: a clinical tool in search of theoretical justification*. J Am Coll Cardiol 1987; 10: 923-929.
11. SOHN DW, CHOI YJ, OH 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): 106-12.
12. CHUNG NS, NISHIMURA RA, HOLMES DR JR, TAJIK AJ: *Measurement of left ventricular dp/dt by simultaneous Doppler echocardiography and cardiac catheterization*. J Am Soc Echocardiogr 1992; 5: 147-152.
13. ROELANDT JRTC: *Farewell Lecture. Beyond the invisible*. The Thoraxcentre Journal 2003; 15; 3: 54-63.