The Cardiology 2(1) : 19-22, 2006

Quantification of Left-to-Right Shunt in 2° ASD by PISA Method

[1]Maryam Esmaeilzadeh, Majid Maleki and Fereidoun Noohi
[1]Department of Echocardiography, Shahid Rajaei Cardiovascular Medical Center,
Iran University of Medical Sciences, Tehran, Iran

Abstract: The purpose of this study was to quantitate the degree of left-to-right shunt in patients with 2° ASD by PISA method in comparison with continuity equation. The PISA method has been used extensively in patients with valvular regurgitation and stenosis for quantitative measurement of regurgitant severity and valve area. But its use in patients with left-to-right shunts including ASD has not been evaluated extensively. We studied 48 consecutive patients with 2° ASD (mean age: 32.5+-4 years; range: 18-54 years). Left-to-Right shunting was quantified by continuity equation and PISA methods. The defect size was between 12-40 mm (mean: 26+- 6). QP/QS by continuity equation was between 1.7-4.5/1 (mean: 2.91) and by PISA method was between 1.6-4.8/1 (mean: 2.92), [r = 0.92, PV= 0.0001]. There was no significant difference between the degree of shunt estimated by continuity equation and PISA method in terms of the defect size and the degree of shunt (PV = 0.179). The PISA method could be as an accurate alternative method of continuity equation for quantitation of the degree of shunt flow in patients with 2° ASD.

Key words: Quantification, left-to-Right shunt, secundum ASD

INTRODUCTION

Accelerating laminar flow patterns has been observed proximal to stenotic, regurgitant and shunt orifices by Doppler color flow mapping by transthoracic and transesophageal echocardiography[1-5] . Flow rate can be calculated from these laminar flow patterns based on the conservation of mass, which assumes that fluid converges uniformly and radially toward a restrictive orifice, forming a series of concentric Isovelocity layers. These Isovelocity surfaces are hemispheric for orifices that are small relative to the region of acceleration[6]. Compared to the turbulent downstream jet; this more predictable pattern of flow in the proximal flow convergence region makes quantitation of regurgitant severity possible. By Doppler color flow mapping, the radius(r) of the Isovelocity surface is measured as the distance from the orifice to the point of color aliasing. Instantaneous flow rate can be calculated as the product of the aliasing velocity V_A at any of these hemispheric contours times the surface area ($2 \pi r^2$) of that shell:

Peak flow rate = $V_A (2 \pi r^2)$

The accuracy of the proximal flow convergence method is highly dependent on precise measurement of the PISA radius, which requires high-resolution imaging and zoom magnification[7]. Proximal flow acceleration thus depends on the severity of regurgitation and the aliasing velocity. Because flow rate is underestimated unless the Nyquist velocity is much less than the orifice velocity, the hemispheric assumption for calculating regurgitant flow rate cannot be used with larger Nyquist velocities[6]. Thus, the hemispheric model is most accurate with larger volume flow rates or with lower aliasing velocities. To improve accuracy, the aliasing velocity can be optimized to better define the hemispheric contour[8,9].

METHODS

Study population: From March 2003 to November 2004 we studied 48 consecutive patients with secundum ASD (33 women and 15 men; mean age: 32.5 + -4.2 years; range,18-54 years), who referred to our institution for evaluation of suitability for device closure.

The exclusion criteria were primum and sinus venosus ASD, partial anomalous pulmonary venous connection and the other associated left-to-right shunts. Transthoracic and multiplane TEE was performed using a commercially available ultrasound system(AQUSEN SEQUOIA, Mountain View, CA 256).All patients gave informed consent.

Echocardiographicstudies: Comprehensive echocardiography and Doppler examination were performed in all the patients. The degree of left-to-right shunt was measured by standard continuity equation using LVOT and RVOT diameters in mid-systole (2-3

Corresponding Author: Esmaeilzadeh M. Shahid Rajaei Cardiovascular Medical Center, Tehran, Iran.

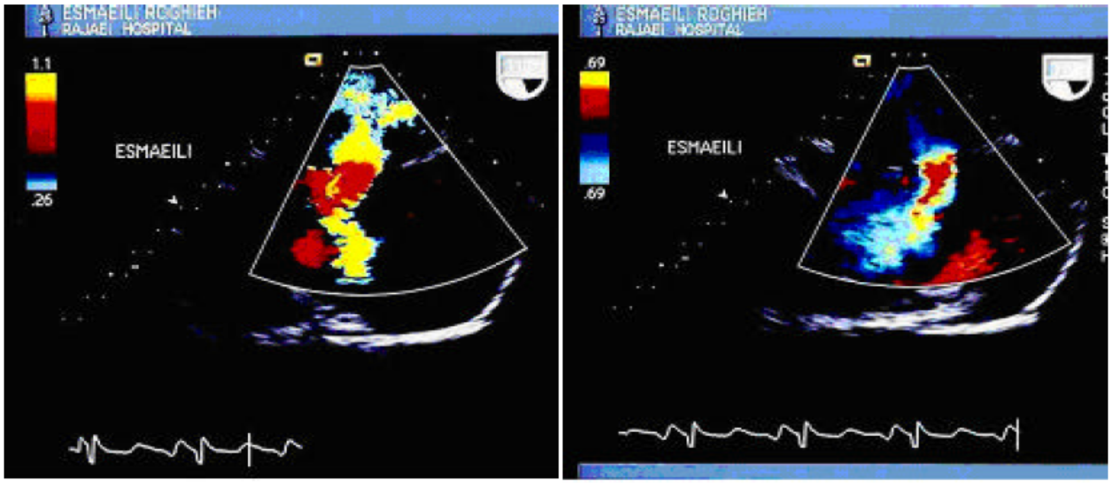

Fig. 1: Transesophageal color flow imaging of Flow Convergence Regions (FCRs) at standard color velocity (a) and by adjusting the Nyquist velocity (b). FCR can be seen to be semicircular, justifying the hemispherical model used in the calculation of flow rate

frames after valve opening) and PW Doppler study for measurement of velocity time integral of LVOT and RVOT. The QP/QS was measured using the following equation:

$$QP/QS = \frac{CSA\ RVOT \times VTI\ RVOT}{CAS\ LVOT \times VTI\ LVOT}$$

Transesophageal echocardiography was done by standard guidelines of the ASE. The atrial septum was examined in multiple planes to achieve three main objectives: Assessment of the Flow Convergence Regions (FCR) proximal to the atrial defect, assessment of the size of the atrial jet in the right atrium and assessment of the size of the atrial defect by two-dimensional echocardiography. The defect size was measured in 0, 45 and 90 degrees and the greatest diameter was recorded as the defect size. By stepwise lowering of the color baseline, aliasing velocities can be reduced to 24-28 cm/sec. The radius of FCRs increases as the aliasing velocity is reduced. FCRs were identified immediately proximal to the defects on the left atrial side of the septum (Fig. 1). The radius (r) of PISA was measured from the first aliasing limit to the orifice in septum. According to the continuity principle, the flow rate across any isovelocity surface in FCR is equal to the flow rate through the orifice. Hence, the maximum instantaneous flow rate through the atrial defect is equal to $2\pi r^2 V_A$ ($2\pi r^2$ is the area of a hemisphere and V_A is the velocity at a radial distance r). In the majority of cases, FCR was largest in size at end of systole.

Pulsed wave Doppler using high-repetition frequency was used to characterize the velocity profile of shunt flow

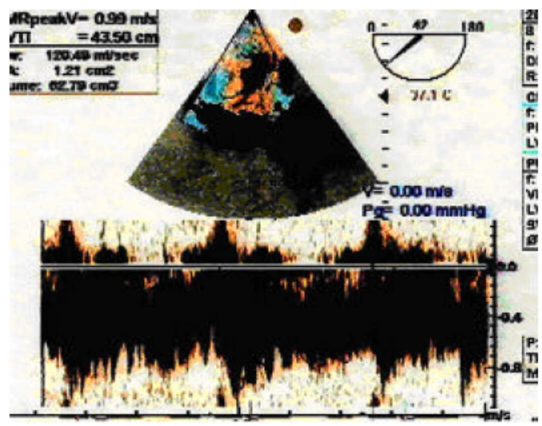

Fig. 2: Peak flow velocity of the jet and Velocity Time Integral (VTI) measured using PW Doppler by positioning the sample volume in the right atrium

in the right atrium. The sample volume was positioned in the color flow jet, close to the septal orifice. The peak flow velocity (V_p) of the jet and velocity time integral (VTI) were measured (Fig. 2).

The flow area of the ASD was calculated as maximum flow rate, divided by maximum flow velocity (Eq. 1).

By dividing the flow to peak ASD flow velocity (V_{peak}), the blood volume across defect would be measured.

$$Flow\ (ASD) = \frac{2\pi_2 \times VA}{Velocity\ (peak)} \quad (1)$$

Shunt Flow = Flow (ASD) x VTI

QP = QS + ASD Volume (by PISA)

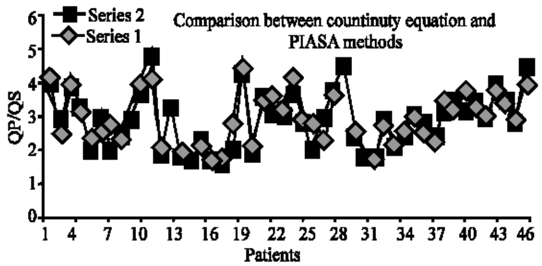

Fig. 3: Comparison of shunt flow estimated by PISA method and continuity equation showed close correlation between two methods

Statistical analysis: Data are presented as mean±SD. The correlation between continuous variables was determined by linear regression analysis. Student's t test and the X^2 test were used as appropriate to compare variables. A value of $p<0.05$ was considered statistically significant. Statistical analysis was performed using a statistical computer software package for social sciences for windows, (released 10.01, SPSS Inc, Chicago, IL- USA).

RESULTS

QP/QS was measured in all the patients by continuity equation except for two patients with associated pulmonary valve stenosis, however there was no limitation for PISA measurement. By continuity equation QP/QS was between 1.7-4.5/1 (mean: 2.91) and by PISA method it was between 1.6-4.8/1 (mean: 2.92). There was no significant difference between the degree of shunt estimated by continuity equation and PISA method in terms of the defect size and the degree of shunt ($p = 0.179$).

Shunt flow determined by PISA correlated closely ($r = 0.92$, $p = 0.0001$) with that determined by continuity equation (Fig. 3).

DISCUSSION

This study shows that left-to-Right atrial shunt can be accurately quantified by multiplane TEE, color flow mapping and the principle of proximal flow convergence. TEE combined with color flow mapping is the most sensitive technique for detecting atrial shunts.

Our study demonstrates that multiplane TEE is highly sensitive for estimating shunt flow across atrial defects, using the proximal flow convergence principle. The atrial septum separates a high pressure chamber (left atrium) from a relatively low pressure chamber (right atrium). The presence of a defect in the septum allows continuous flow throughout the cardiac cycle from left to right. Flow through the defect is unaffected by competitive flow as mitral valve flow is at right angles to shunt flow. This means that the atrial defect can be closely approximated to a planar orifice. Thus, the principles of flow convergence relating to laminar flow through a circular and planar orifice appear eminently applicable to atrial shunt flow. Hydrodynamic theory predicts the Flow Convergence Regions (FCRs) to be hemispheric in such cases. The validity of this theoretical assumption appeared to be justified is practice. FCRs were found on TEE color flow mapping to be semicircular or nearly so on both transverse and longitudinal planes. This also accounts for the excellent correlation between measurements in these two orthogonal planes. However, it is not necessary for orifices to be circular for this method to be valid. Rodriguez *et al*.,[10] demonstrated that volume flow rate in vitro can be calculated assuming hemispheric geometry, irrespective of orifice shape. Utsunomiya *et al*.,[11] on the other hand, found that the hemispherical model underestimates flow rate when orifices are noncircular. They used a hemielliptic model and concluded that differences in planar orifice shape do not affect calculation of volume flow rate. The use of multiplane TEE is a major strength to this study. High-frequency transducers improve spatial resolution and enable lower aliasing velocities to be used. This, coupled with baseline shifting of color flow maps, allowed FCRs to be maximized in size. Another advantage of TEE is its ability to image the atrial septum at right angles to the ultrasound beam. FCRs thus could be optimally visualized and flow across the septum could be assessed accurately by pulsed Doppler without the need for angle corrections.

Our study shows that shunt calculated by the flow convergence method correlates closely with that calculated by two-dimensional echocardiography and pulsed Doppler (continuity equation). The two-dimensional echocardiography method, in contrast, relies on accurate determination of LVOT and RVOT diameters. Furthermore, FCRs proximal to the defects generally are easy to visualize. In addition, the jets in the right atrium interact with flow from four sources: Superior and inferior vena cava, coronary sinus and tricuspid regurgitation. The latter was present in all of our patients and the jets often were seen to be directed toward the atrial septum, where they interacted with atrial jets.

In some cases tricuspid regurgitant jets entering the defects in the septum and causing right-to-left shunting. These limitations are overcome by the flow convergence method. FCRs are zones of laminar accelerating flow proximal to the shunt orifice and thus are independent of factors operating in the distal receiving chamber.

Bargiggia *et al.*,[12] studied 52 patients with mitral regurgitation and showed that the maximum regurgitant flow rate correlated closely (r = 0.91) with angiographic grading. They also demonstrated a good correlation (r = 0.93) with angiographic regurgitant volume in 15 patients. Moises et al[13] also showed that maximal flow rate correlates closely with shunt flow through ventricular septal defects.

Using the flow convergence technique to assess atrial shunt should be relatively easy in clinical practice. Adjustments of color flow maps are not always necessary. In our study, all patients had FCRs that were clearly visible even without adjusting the color flow maps. The larger the FCRs, the greater were the magnitude of shunting.

That the PISA is valid as well is demonstrated by the good correlation between shunt derived by this technique and that calculated by continuity equation.

CONCLUSION

This study shows that the principle of flow convergence (PISA) combined with TEE provides accurate and easily derived quantitative information on atrial shunt flow and would be as an alternative method of continuity equation. It is quick, reliable and simple enough to be incorporated into routine clinical practice and highly recommended in patients with significant pulmonary regurgitation, pulmonary stenosis and poor image view of pulmonic valve.

REFERENCES

1. Rodriguez, L., J.D. Thomas and V. Monterroso, *et al.*, 1993. Validation of the proximal flow convergence method: Calculation of orifice area in patients with mitral stenosis. Circulation, 88: 1157-1165.
2. Barigiggia, G.S., L. Tronconi and D.J. Sahn, *et al.*, 1991. A new method for quantitation of mitral regurgitation based on color flow Doppler imaging of flow convergence proximal to regurgitant orifice. Circulation, 84: 1481-1489.
3. Recusani, F., 1991. Noninvasive assessment of left ventricular function with continuous wave Doppler echocardiography [Editorial, comment]. Circulation 83: 2141-2143.
4. Moises, V.A., B.C. Maciel and L.K. Hornberger, *et al.*, 1991. A new method for noninvasive estimation of ventricular septal defect shunt flow by Doppler color flow mapping: Imaging of the laminar flow convergence region on the left septal surface. J. Am. Coll Cardiol, 18: 824-832.
5. Rittoo, D., G.R. Sutherland and T.R. Shaw, 1993. Quantitation of left-to-Right atrial shunting and defect size after balloon mitral commissurotomy using biplane transesophageal echocardiography, color flow mapping and the principle of proximal flow convergence. Circulation, 87: 1591-1603.
6. Rodriguez, L., J. Anconina and F.A. Flachskampf, *et al.*, 1992. Impact of finite orifice size on proximal flow convergence: Implications for Doppler quantitation of valvular regurgitation. Circ Res., 70: 923-930.
7. Recusani, F., G.S. Bargiggia and A.P. Yoganathan, *et al.*, 1991. A new method for quantitation of regurgitant flow rate using color Doppler flow imaging of the flow convergence region proximal to a discrete orifice: An *In vitro* study. Circulation, 83: 594-604.
8. Xie, G.Y., M.R. Berk and C.S. Hixson, *et al.*, 1995. Quantification of mitral regurgitant volume by the color Doppler proximal Isovelocity surface area method: A clinical study. J. Am. Soc. Echocardiogr., 8: 48-54.
9. Zhang, J., M. Jones and R. Shandas, *et al.*, 1993. Accuracy of flow convergence estimates of mitral regurgitation flow rates obtained by use of multiple color flow Doppler M-mode aliasing boundaries: An experimental animal study. Am. Heart J., 125: 449-458.
10. Rodriguez, L., F.A. Flachskampf, V.M. Abascal, R.A. Levine, P. Harrigan and J.D. Thomas, 1989. Regurgitant flow rate calculated by the proximal isovelocity surface area is independent of orifice shape. Circulation, 80: II-570.
11. Utsunomiya, T., T. Ogawa, R. Doshi, D. Patel, M. Quan, W. Henry and J.M. Gardin, 1991. Doppler color flow proximal isovelocity surface area method for estimating volume flow rate: Effects of orifice shape and machine factors. J. Am. Coll. Cardiol., 17: 1103-1111.
12. Bargiggia, G.S., L. Tronconi, D.J. Sahn, F. Recusani, A. Raisaro, S. De Servi, L.M. Valdes-Cruz and C. Montemartini, 1991. A new method for quantitation of mitral regurgitation based on color flow Doppler imaging of flow convergence proximal to regurgitant orifice. Circulation, 84: 1481-1489.
13. Moises, V.A., B.C. Maciel, L.K. Hornberger, A. Murillo-Olivas, L.M. Valdes-Cruz, D.J. Sahn and R.G. Wientraup, 1991. A new method for noninvasive estimation of ventricular septal defect shunt flow by Doppler color flow mapping: Imaging of laminar flow convergence region on the left septal surface. J.Am. Coll Cardiol., 18: 824-832.