Homograft Pulmonic Stenosis After the Ross Procedure: Evaluation of the Stenotic Valve Area by Proximal Isovelocity Surface Area (PISA)

Paul A. Tunick, MD, and Itzhak Kronzon, MD, *New York City, New York*

The proximal isovelocity surface area (PISA) technique has been used to evaluate valvular regurgitant flow, regurgitant orifice area, and stenotic valve area. This report shows the usefulness of this Doppler technique in quantifying the stenotic valve area of a pulmonic valve homograft prosthesis after the Ross procedure. The patient was a 35-year-old man who had a Ross procedure 3 years earlier for aortic stenosis, which included replacement of the pulmonic valve with a cryopreserved homograft pulmonic valve. With an aliasing velocity set at 40 cm/s and a PISA radius of 1.1 cm, the pulmonic valve area was calculated as follows: Pulmonic valve peak flow rate = 2 × 3.14 × 1.12 × 40 = 304 mL/s; Pulmonic valve area = Peak flow rate / Peak velocity = 284/350 = 0.87 cm². (J Am Soc Echocardiogr 2001;14:67-9.)

The Ross procedure has emerged as an alternative to routine aortic valve replacement.[1] Because the patient's pulmonic valve and a segment of pulmonary artery are transplanted into the aortic position, the pulmonic valve is replaced by a homograft. The subsequent development of stenosis of the pulmonic valve homograft is uncommon and has been reported in 4% of patients[2] (and in 12% of patients with homograft valve conduits used to repair the right ventricular outflow tract in various congenital defects[3]). The proximal isovelocity surface area (PISA) technique has been used over the past decade to add information about valvular regurgitant flow, regurgitant orifice area, and stenotic valve area, which can be obtained noninvasively with Doppler echocardiography.[4,5] This report shows the usefulness of this technique in quantifying the stenotic valve area of a pulmonic valve homograft prosthesis after the Ross procedure.

CASE REPORT

The patient was a 35-year-old man who had surgery for severe aortic stenosis (bicuspid valve) 3 years earlier. A Ross procedure was performed, with pulmonary artery/pulmonic valve transplantation for the aortic valve replacement and a cryopreserved homograft replacement of the pulmonic valve. Postoperatively, aortic insufficiency was noted, which worsened significantly over the next 2 years, resulting in significant left ventricular dilatation (7 cm). He subsequently underwent aortic valve replacement with a No. 29 Carpentier-Edwards (Edwards Lifesciences Corp, Irvine, Calif) pericardial valve. Echocardiography, performed because of a systolic murmur, revealed a normally functioning aortic tissue prosthesis and high flow velocity across the pulmonic valve homograft (Figure 1). The peak systolic flow velocity was 350 cm/s, and the calculated peak gradient was 50 mm Hg. With an aliasing velocity set at 40 cm/s and a PISA radius of 1.1 cm, the pulmonic valve area was calculated as follows:

$$\text{Pulmonic valve peak flow rate} = 2 \times 3.14 \times 1.1^2 \times 40 = 304 \text{ mL/s}$$

$$\text{Pulmonic valve area} = \text{Peak flow rate} / \text{Peak velocity} = 284 / 350 = 0.87 \text{ cm}^2$$

Because the patient was asymptomatic, no further treatment was advised at that time.

DISCUSSION

Color Doppler flow mapping generates a visual depiction of blood moving within the heart and blood vessels. The ultrasound beam returning from moving blood has a Doppler shift in frequency, and this is displayed as a color signal. In addition, the Doppler shift is determined by blood flow velocity,

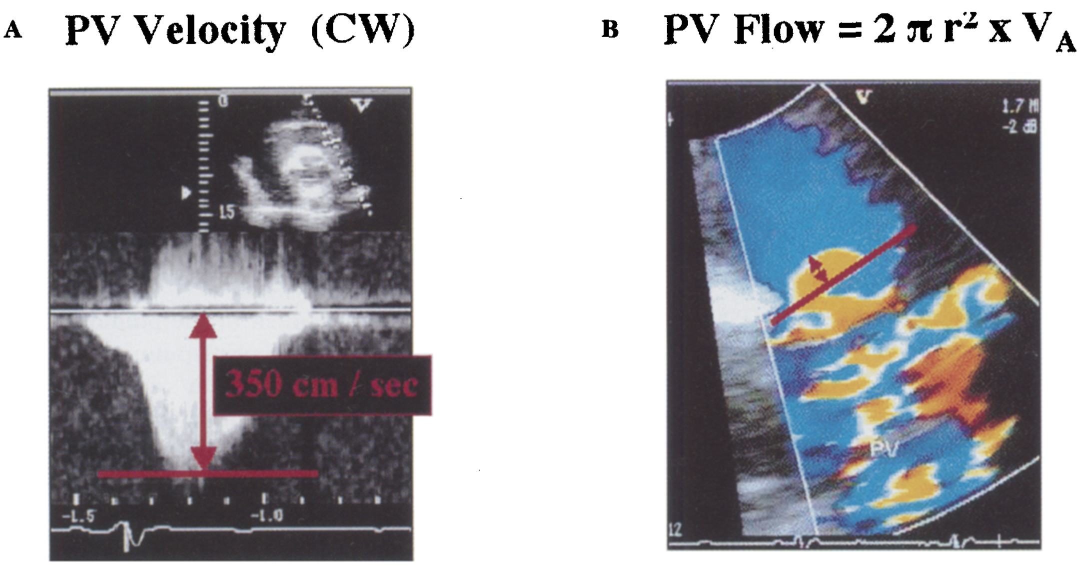
From the Noninvasive Cardiology Laboratory, Department of Medicine, New York University School of Medicine, New York City.

Reprint requests: Itzhak Kronzon, MD, 560 First Avenue, New York City, NY 10016.

0894-7317/2001 $35.00 + 0 27/4/106207

doi:10.1067/mje.2001.106207

Journal of the American Society of Echocardiography
January 2001



$$\text{PV Flow} = 2 \times 3.14 \times 1.1^2 \times 40 = 304 \text{ cc / sec}$$

$$\text{PVA} = \text{Flow} / V = 304 / 350 = 0.87 \text{ cm}^2$$

Figure 1 A, Continuous wave Doppler of flow velocity across the pulmonic valve homograft. The peak flow velocity is 350 cm/s. **B,** Color Doppler of flow velocity across the pulmonic valve homograft. The *red line* represents the level of the valve. The *arrowheads* demarcate the proximal isovelocity surface area radius. *PV,* Pulmonic valve; *CW,* continuous wave Doppler; *r,* radius; V_A, aliasing velocity; *Cc,* cubic centimeters; *V,* velocity; *PVA,* pulmonic valve area.

which can be measured quantitatively with the use of a spectral tracing. The visual color flow signal is used routinely to estimate the severity of valvular regurgitation, and the flow velocity (V) is used clinically to estimate valvular gradient (ΔP) by the simplified Bernoulli formula: $\Delta P = 4V^2$.

The PISA technique is a newer method[4,5] that may add quantitative information to the estimation of valvular regurgitation and stenosis. It takes advantage of the fact that blood flowing from a higher pressure chamber to a lower pressure chamber, through a stenotic valve or regurgitant orifice, accelerates proximal to the orifice. This laminar flow acceleration can be seen on color Doppler imaging. The flow converges proximally toward the center of a stenotic or regurgitant orifice, and the area of flow convergence can be quantitated because as the orifice area narrows, the flow velocity increases along streamlines. At differing velocities approaching the orifice, the display changes color abruptly (referred to as *aliasing*) in hemispheres with a measurable radius. The surface area (PISA) of each hemispheric "shell" can therefore be calculated. If this area is multiplied by the velocity at which the color changes (the aliasing velocity), this yields a quantitative estimation of the amount of blood flow passing through the orifice. Thus regurgitant or forward flow may be calculated:

$$\text{(Regurgitant or forward) Flow} = 2 \times \pi r^2 \times \text{Aliasing velocity}$$

Similarly, the regurgitant orifice area may be calculated. For the sake of convenience, the largest PISA for a given aliasing velocity is used (yielding the maximum, or peak, instantaneous flow) along with the peak flow velocity, to give a measurement of the regurgitant orifice area:

$$\text{Regurgitant orifice area} = \text{Peak regurgitant flow} / \text{Peak flow velocity}$$

In patients with valvular regurgitation, these calculations yield information that is complementary to the semiquantitative visual estimation of regurgitation on color Doppler, which is in common clinical use.

For the estimation of stenotic valve area, the forward flow volume obtained in the same manner can be divided by the flow velocity passing through the valve (from the spectral continuous wave Doppler):

$$\text{Valve area} = \text{Peak forward flow rate} / \text{Peak flow velocity}$$

In addition to mitral and aortic regurgitant flow,[6,7] the PISA method has been used to measure mitral valve area in patients with mitral stenosis,[8] shunt flow in patients with ventricular septal defect,[9] and normal prosthetic mitral valve area.[10]

We used the PISA method for the measurement of pulmonic valve area. This area may also be calculated with the continuity equation. When the flows through 2 parts of the heart are equal, and the area of 1 part can be directly measured, this information can be used to obtain valve area:

$$\text{Pulmonic valve area} = (\text{RVOT area} \times \text{RVOT velocity}) / \text{Pulmonic velocity}$$

However, the accuracy of the continuity equation depends on an accurate measurement of the area of the right ventricular outflow tract (RVOT) (or alternatively of the mitral or tricuspid ring or the left ventricular outflow tract), and these measurements may be inexact. Therefore the PISA method may add quantitative information, and in this report it has been used to demonstrate the severity of stenosis in a prosthetic (homograft) pulmonic valve.

REFERENCES

1. Gula G, Wain WH, Ross DN. Ten years' experience with pulmonary autograft replacements for aortic valve disease. Ann Thorac Surg 1979;28:392-6.
2. Ward EK, Elkins RC, Overholt ED, Knott Craig CJ, Razook JD, Lane MM, et al. Evaluation of cryopreserved homografts in the right ventricular outflow tract after the Ross procedure: intermediate-term follow up. J Heart Valve Dis 1997;6:130-3.
3. Cleveland DC, Williams WG, Razzouk AJ, Trusler GA, Rebeyka IM, Duffy L, Kan Z, Coles JG, Freedom RM. Failure of cryopreserved homograft valved conduits in the pulmonary circulation. Circulation 1992;86(5 Suppl):II150-3.
4. Recusani F, Bargiggia GS, Yoganathan AP, Raisaro A, Valdes-Cruz LM, Sung HW, et al. A new method for quantification of regurgitant flow rate using color Doppler flow imaging of the flow convergence region proximal to a discrete orifice: an in vitro study. Circulation 1991;83:594-604.
5. Utsunomiya T, Ogawa T, Tang HA, Doshi R, Patel D, Quan M, et al. Doppler color flow mapping of the proximal isovelocity surface area: a new method for measuring volume flow rate across a narrowed orifice. J Am Soc Echocardiogr 1991; 4:338-48.
6. Yamachika S, Reid CL, Savani D, Meckel C, Paynter J, Knoll M, et al. Usefulness of color Doppler proximal isovelocity surface area method in quantitating valvular regurgitation. J Am Soc Echocardiogr 1997;10:159-68.
7. Tribouilloy CM, Sarano E, Fett SL, Bailey KR, Seward JB, Tajik AJ. Application of the proximal flow convergence method to calculate the effective regurgitant orifice area in aortic regurgitation. J Am Coll Cardiol 1998;32:1032-9.
8. Oku K, Utsunomiya AT, Mori H, Yamachika S, Yano K. Calculation of mitral valve area in mitral stenosis using the proximal isovelocity surface area method: comparison with two-dimensional planimetry and Doppler pressure half time method. Jpn Heart J 1997;38:811-9.
9. Kurotobi S, Sano T, Matsushita T, Takeuchi M, Kogaki S, Miwatani T, et al. Quantitative, non-invasive assessment of ventricular septal defect shunt flow by measuring proximal isovelocity surface area on colour Doppler mapping. Heart 1997;78:305-9.
10. Leung DY, Wong J, Rodriguez L, Pu M, Vandervoort PM, Thomas JD. Application of color Doppler flow mapping to calculate orifice area of St Jude mitral valve. Circulation 1998;98:1205-11.