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EDITORIAL COMMENT

The Importance of Regurgitant Orifice Shape in Mitral Regurgitation*

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When you cannot measure it, . . . your knowledge is of a meagre and unsatisfactory kind; it may be the beginning of knowledge, but you have scarcely . . . advanced to the state of Science, whatever the matter may be.

—Kelvin (1)

In 1951, Gorlin and Gorlin (2) proposed the hydraulic orifice equation, based on the simple formula that orifice area equals flow divided by velocity.

$$A = F/V \qquad [1]$$

Their idea was to calculate orifice area of stenotic heart valves from measurements of flow and velocity. Flow could be assessed by indicator-dilution methods, but velocity could not be measured because Doppler ultrasound had not yet been invented. Therefore, the Gorlins proposed to calculate velocity from the pressure gradient, using the Torricelli law. For most of the 6 decades since their seminal paper, the Gorlin equation has been used to calculate the orifice area in mitral and aortic stenosis. Levine and Gaasch (3) showed that the Gorlin equation could be used to calculate regurgitant volume (RgV) in regurgitant lesions such as mitral regurgitation (MR):

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$$RgV = ROA \times C_d \times \sqrt{MPG} \times T \qquad [2]$$

In Equation 2, ROA is regurgitant orifice area, C_d is a discharge coefficient accounting for energy loss, $\sqrt{MPG}$ is the square root of the mean pressure gradient, and T is the time over which regurgitation occurs. Equations 1 and 2 can be rewritten as follows:

$$ROA = RgV/VTI \qquad [3]$$

where RgV is regurgitant volume in milliliters and VTI is the velocity-time integral of the regurgitant jet in centimeters, as determined by Doppler ultrasound. VTI incorporates the mean gradient and the duration of regurgitant flow and is primarily determined by the systolic pressure difference between the left ventricle (LV) and left atrium (LA). VTI is independent of MR severity and generally falls within a fairly narrow range of values (except in acute MR, where the pressure gradient between the LV and LA is low). Thus, the 2 primary determinants of MR severity are ROA and RgV, which are linearly related. RgV can also be expressed as regurgitant fraction (RgF), which is the percentage of the total stroke output of the LV that is ejected retrograde into the LA. According to both the American Society of Echocardiography (4) and the American College of Cardiology/American Heart Association guidelines (5), ROA, RgV, and RgF are used together to determine MR severity.

In this issue of *iJACC*, Buchner et al. (6), report differences in the shape of the ROA in patients with MR of different etiologies. The investigators used cine cardiac magnetic resonance (CMR) to directly visualize the ROA in 74 patients with MR due to

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varying causes. MR severity was classified as mild (n = 29), moderate (n = 20), or severe (n = 25) using RgF calculated by CMR. Etiology of MR was considered degenerative in 19 patients, leaflet prolapse in 15, flail leaflet in 25, and functional (secondary to LV dysfunction) in 15. The term "degenerative" was used unconventionally in this study to describe thickened, scarred leaflets, which are usually due to rheumatic heart disease, other post-inflammatory conditions, or anorectic drug use. The term "degenerative" is usually reserved for prolapse or flail leaflets due to myxomatous degeneration of leaflet and subvalvular tissues. Despite this faux pas, the investigators show convincingly that ROA is seldom circular in MR, but is elliptical or slitlike, particularly in functional MR. ROA shape index, defined as the long-axis divided by the short-axis of the elliptical ROA, was significantly larger for functional MR (3.9) than for mitral valve prolapse (2.1), flail (2.2), or "degenerative" etiology (1.2). Given that orifice shape is not a component of the hydraulic orifice equation, and therefore not a primary determinant of MR severity, is this finding clinically relevant?

To answer this question, one must consider that echocardiography has become the clinical standard for assessing MR severity. In clinical practice, MR severity is most often graded by "eyeballing" the size of regurgitant jet in the LA using color Doppler imaging. This is unfortunate because this method has been known to be inaccurate for 2 decades and is discouraged in the American Society of Echocardiography guidelines (4). In a recent report from our institution, almost one-half of patients referred for percutaneous treatment of severe MR with the MitraClip device (Abbott Vascular, Abbott Park, Illinois), did not have severe MR (7). The size of the color Doppler regurgitant jet within the LA is dependent on too many variables, including instrument settings, hemodynamics, jet eccentricity, and orifice geometry (4). With regard to the latter, slitlike orifices are analogous to placing one's thumb over a water hose, creating a spray that may appear very large on color Doppler imaging. Moreover, when MR occurs through 2 separate orifices, color Doppler jets appear larger than would be expected for a single orifice of the same area (8). A good example of both situations is the bileaflet mechanical prosthetic valve, in which 3 separate regurgitant jets are seen in the LA during systole. Sometimes, these jets can appear fairly large, yet clinicians know that this is "trace" or "physiological" MR, and jet size is ignored.

Because of the known limitations of regurgitant jet area in evaluating MR severity, efforts have focused on imaging the ROA, either by vena contracta measurement, or by calculation from the size of the proximal isovelocity surface area (PISA) region (4). The vena contracta is the high velocity flow stream at or just downstream to the ROA. It conforms to ROA shape but is slightly smaller. Vena contracta width is a 1-dimensional measurement of the diameter of the ROA, which can be misleading if the ROA is not round. The vena contracta should be measured in a long-axis view, perpendicular to the largest diameter of the elliptical ROA (9). PISA calculation assumes a hemispheric shape to the proximal flow convergence region, which is only true for relatively round orifice shapes. Slitlike orifice shapes, such as those seen in functional MR, do not have a hemispheric PISA, which leads to underestimation of ROA (10,11). Even when vena contracta and PISA are carefully performed, significant interobserver variability exists in grading MR severity (12). Clearly, the best way to measure ROA is direct visualization by 3-dimensional (3D) imaging techniques. This has been done successfully with both 3D echocardiography (13–16) and with CMR (17).

Despite the ability to directly image the regurgitant orifice by CMR or 3D echocardiography, there are still challenges to overcome. Both methods use tomographic slices that are oriented 3 dimensionally. The actual ROA may curve out of the imaging plane. If there is more than 1 ROA, they may not be in the exact same imaging plane. Imaging artifacts such as Doppler blooming or CMR flow voids can be problematic. Temporal resolution must also be considered. In holosystolic MR, the ROA is dynamic and should ideally be measured as a mean value over systole. In mitral prolapse, MR may occur only in late systole, such that a single frame image of the ROA may significantly overestimate MR severity. Thus, it is important to consider both RgV and ROA to get a complete understanding of the severity of MR.

CMR provides a comprehensive evaluation of MR. ROA and RgV are the primary mathematical determinants of MR severity, and both can be measured quantitatively by CMR (18). In addition, LV volumes and ejection fraction are important in MR (5), and CMR is generally accepted as the most robust and reproducible clinical method for measuring them. Functional MR is a disease of the LV, in which structurally normal leaflets are restricted by ventricular enlargement, regional wall motion abnormalities, and/or symmetrical or asymmetrical annular dilation. As shown in the Buchner et al. study (6), CMR offers the ability to measure leaflet tenting area, tethering distance, and the mitral annulus. Thus, CMR can evaluate the mechanism and severity of MR, as well as its impact on the LV.

Since the publication of the Sellers angiographic criteria (19), MR severity has been assessed qualitatively. Published guidelines (4,5) even recommend converting the quantitative measure of ROA, RgV, and RgF into descriptive categories such as mild, moderate, severe, or 1+ to 4+ on an ordinal scale. Even though such descriptive categories are clinically meaningful ("mild" vs. "severe" MR), we now have imaging tools capable of accurate measurement of the quantitative, mathematical determinants of MR severity. To fully understand the complex pathophysiology of MR and evaluate new surgical or percutaneous therapies, it is important to be able to measure MR quantitatively.

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