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EDITORIAL COMMENT

The Vena Contracta Area

Conquering Quantification With a 3D Cut?*

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The vena contracta concept. The accurate and reproducible quantification of mitral regurgitation (MR) remains a common clinical challenge. In recent years, 3-dimensional (3D) echocardiography has provided a new perspective on mitral valve morphology and function. One of the MR flow parameters being re-examined in this new light is the vena contracta (VC) area. In engineering parlance, the free jet theory describes the behavior of flow events with negligible wall effects, such as the typical flow conditions of MR (1).

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According to this theory, as a regurgitant jet passes through an orifice (the anatomic orifice), the jet continues to constrict for a certain length then expands radially into the receiving chamber. The VC is the point at which the jet has its minimal area. Note that this area occurs immediately distal to the orifice and not before or within the regurgitant orifice—a practical detail often missing from described methodologies. In addition to being distal to the anatomic orifice, the VC area is also smaller than the anatomic orifice. In the clinical setting, the VC area can be up to 40% smaller than the anatomic orifice, and the factors that influence the magnitude of this ongoing flow (and area) contraction include the geometry of the anatomic orifice (which is highly variable) and the fluid viscosity (less variable) (2). In clinical terms, this explains why the VC area is considered equivalent to the effective regurgitant orifice area (EROA). The location and size of the VC area is highly dependent on the geometry of the mitral valve orifice and largely independent of flow rate (1,3).

Current imaging guidelines suggest that regurgitation severity can be approximated by measuring the diameter of the VC (4). However, when the regurgitation occurs through an asymmetric orifice, such as in functional MR, then the validity of a single 2-dimensional (2D) diameter of such complex jet geometry is limited. It has long been recognized that a measure of the VC area would be a preferred measurement, but a short-axis depiction of the VC area could not be reliably displayed using 2D color Doppler methods (3). With the recent advent of 3D color Doppler imaging, we can now employ any-plane cropping of the volumetric data to identify the true cross-sectional area of the VC—a direct measure of the EROA.

Building the case for clinical application. Several important imaging studies have helped build a case for the routine use of VC area to estimate a single EROA in patients with either organic or functional MR. In an early study, 3D transthoracic echo was used to demonstrate that 3D VC area measurement was feasible and relatively quick to perform, and demonstrated a better relation to Doppler-derived EROA than did 2D VC diameter in patients with clinically significant MR (5). In patients with functional MR, Marsan et al. (6) used very similar methodology to define the VC area and then multiplied it by the time velocity integral (TVI) of the regurgitant mitral jet to derive regurgitant volume. This VC area–derived regurgitant volume showed excellent correlation with cardiac magnetic resonance (CMR) measures of regurgitant volume and demonstrated that there was no significant

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volume difference between techniques (mean difference of <1 ml/beat). In a recent study, Shanks et al. (7) measured VC area by 3D transesophageal echocardiography (TEE) and also compared it with CMR. They demonstrated that 2D TEE significantly underestimated the EROA and the regurgitant volume by 22% when compared with either 3D TEE or CMR. By contrast, 3D TEE measures of VC area led to an underestimate of the regurgitant volume by only 1.2%. Finally, in a recent study by Zeng et al. (8), direct planimetry of the VC area was compared with an integration of 2D methods as reference. This study also demonstrated significant differences in VC area among patients with different MR grades. A VC area cutoff of 0.41 cm^2 reliably differentiated severe from moderate MR. This VC area cutoff is entirely consistent with the current guidelines stating that an EROA >0.4 cm^2 indicates severe MR (4), along with minimal interobserver and intraobserver variability (8). From these studies, and from ongoing clinical experience, it is now clear that the VC area can be accurately assessed by 3D TTE or 3D TEE methods and that this directly measured area correlates well with accepted 2D Doppler and CMR standards used to quantify MR severity.

A quantitative solution for the multijet? Having now assessed the qualitative performance of the VC area measurement against a variety of reference standards and across a range of MR conditions, perhaps the final frontier is to assess the VC area of multiple MR jets. In this issue of *iJACC*, Hyodo et al. (9) test the performance of VC area measures in a patient cohort with functional MR and at least 2 distinct jets of MR. The study group comprised 64 patients who underwent transesophageal 3D matrix TEE just prior to aortic (n = 49) or mitral (n = 15) valve surgery. Since this was a pre-operative study, the investigators were able to employ a unique reference standard: cardiac stroke volume measured with the thermodilution technique. For each patient, the mitral regurgitant volume was defined by subtracting the total left ventricular stroke volume, as assessed by 3D echo, from the systemic stroke volume, by the thermodilution method. A reference standard for the EROA was thus calculated as the total regurgitant volume (cm^3) divided by the TVI (cm) of a single MR Doppler signal.

The study by Hyodo et al. (9) has several important findings. The vast majority (94%) of the identified VC areas were highly asymmetric. This observation is somewhat expected since prior studies have demonstrated a crescentric leaflet coaptation defect in functional MR (5,6), but this observation does demonstrate the inadequacy of the geometric assumptions implicit in the application of 2D color measurement of a single VC diameter. In this study of multiple MR jets, 2D VC diameter method had only a modest correlation to the unique reference standard of EROA based on thermodilution (R = 0.56). By contrast, the summation of 2 or more VC areas had a strong correlation to the reference standard (R = 0.90). In the subgroup of patients with 3 distinct MR jets, the VC area method continued to demonstrate strong reference standard correlation (R = 0.91), whereas the 2D VC diameter method did not (R = 0.46). Although the correlation between summed VC area and the reference standard is impressive, it must be acknowledged that this comparison was performed under nearly ideal clinical circumstances, including a breath hold to limit 3D color Doppler stitch artifact. In addition, the reference standard for EROA was in fact a composite measure of 3 different events (RV stroke $volume_{Thermodilution}$, LV stroke $volume_{3D\ Volumes}$, and MR_{TVI}). As such, the degree of correlation between summed 3D VC areas and this composite reference standard for EROA is quite remarkable. In short, the study of Hyodo et al. (9) is an important addition to a growing body of work describing the appropriate clinical conditions for the application of this fairly new 3D color Doppler measurement. This study is the first to demonstrate that when more than 1 MR jet is present, the VC areas can be simply added together to approximate the total EROA.

The VC area—impressive, but not perfect. The size of the VC is considered to be independent of flow rate, and largely dependent on the size of the regurgitant orifice (1,3,5). However, when applied clinically, the accuracy of 3D color Doppler measures of the VC area can be affected by several user and machine settings, such as color Doppler gain, and the write-priority algorithm employed by the image display software. This adjustable software algorithm controls whether a given region of volumetric data at the tissue/blood interference is displayed as either tissue (B mode image) or flowing blood (color Doppler). If the write-priority algorithm is adjusted in favor of color Doppler, then the VC area will appear larger. Only some software vendors provide user control over this fundamental display setting. More common for the user, is the ability to readily adjust the tissue gain settings either before or after image acquisition. In a similar fashion, these gain settings can have a profound effect on the size of the