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● *Original Contribution*

# ANATOMICAL REGURGITANT ORIFICE DETECTION AND QUANTIFICATION FROM 3-D ECHOCARDIOGRAPHIC IMAGES

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**Abstract—The vena contracta and effective regurgitant orifice area (EROA) are currently used for the clinical assessment of mitral regurgitation (MR) from 2-D color Doppler imaging. In addition to being highly user dependent and having low repeatability, these methods do not represent accurately the anatomic regurgitant orifice (ARO), which affects the adequate assessment of MR patients. We propose a novel method for semi-automatic detection and quantitative assessment of the 3-D ARO shape from 3-D transesophageal echocardiographic images. The algorithm was tested on a set of 25 patients with MR, and compared with EROA for validation. Results indicate the robustness of the proposed approach, with low variability in relation to different settings of user-defined segmentation parameters. Although EROA and ARO exhibited a good correlation ($r = 0.8$), relatively large biases were measured, indicating that EROA probably underestimates the real shape and size of the regurgitant orifice. Along with the higher reproducibility of the proposed approach, this highlights the limitations of current clinical approaches and underlines the importance of accurate assessment of the ARO shape for diagnosis and treatment in MR patients. (E-mail: msotaquira@usbbog.edu.co) © 2017 World Federation for Ultrasound in Medicine & Biology.**

*Key Words:* **Three-dimensional echocardiography, Mitral regurgitation, Anatomical regurgitant orifice, Region competition, Max-flow, Min-cut.**

## INTRODUCTION

Valvular heart disease, the damage or alteration in morphology and function of any of the four heart valves, represents an important public health issue. Epidemiologic studies from United States and Europe (Iung 2003; Nkomo et al. 2006) have reported that more than one in eight patients aged ≥75 years have moderate or severe valvular disease and stress the importance of early identification and quantification of its severity. One of the most common valvular pathologies is mitral regurgitation (MR), a growing public health problem (Enriquez-Sarano et al. 2009), which occurs when the mitral valve cannot close properly during systole, thus originating backflow of blood from the left ventricle into the left atrium.

Current guidelines for the quantitative assessment of MR recommend the use of 2-D color-Doppler flow imaging for the estimation of the vena contracta (VC) and the effective regurgitant orifice area (EROA) (Lancellotti et al. 2010; Zoghbi et al. 2003). The VC is defined as the narrowest portion of the regurgitant jet as seen from a 2-D cut-plane perpendicular to the commissural line of the valve, whereas the EROA is an indirect method for estimation of the size of the anatomical regurgitant orifice (ARO) relying on the assumption that the regurgitant blood flow converges into a hemispherical shape. Although the ARO is currently used in the assessment of MR severity, its intrinsic 3-D nature and non-circular, non-planar shape (Enriquez-Sarano et al. 2009; Little 2012; Little et al. 2007, 2008) make estimation of the VC and EROA highly unreliable and poorly reproducible (Biner et al. 2010; Shanks et al. 2010; Yosefy et al. 2009; Zeng et al. 2011).

The recent advent of 3-D color Doppler allows direct planimetry of the regurgitant orifice but only an approximate estimation of the real orifice size, given its non-planar shape (Chandra et al. 2011; Grayburn 2011). In addition, correct visualization of the orifice can be affected by user and machine settings, such as

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color-Doppler gain, long electrocardiography-gated multibeat acquisitions and volume rate, resulting in a user-dependent imaging technique (Little et al. 2008).

Some computational approaches aimed at semi-automatically segmenting the ARO and reducing user interaction have recently been proposed (Chandra et al. 2009, 2011; Grady et al. 2011; Moraldo et al. 2013). Chandra et al. (2009, 2011) computed the ARO area from 3-D transesophageal echocardiographic (TEE) images using manual tracing of the mitral leaflets followed by automatic computation of the surface corresponding to the 3-D regurgitant orifice. However, the method is time consuming (on average, 6 min per data set) and has low reproducibility. On the other hand, Grady et al. (2011) proposed a method that operates directly on the 3-D color-Doppler data set, requiring one user-defined point to locate the valve, followed by a color segmentation algorithm that allows estimation of EROA. Despite eliminating assumptions on the shape of the regurgitant orifice, custom-made hardware and fine setting of the acquisition parameters are required to achieve accurate results. Finally, Moraldo et al. (2013) proposed a method for automatically measuring the rate of increase in flow velocity with distance using 2-D color image segmentation techniques with accurate results and requiring a total of 40 2-D color-Doppler frames per patient. However, the method has the same limitations of the EROA technique because it also relies on assumptions on the geometry of the regurgitant jet.

To address the limitations of these approaches, we aimed to develop a novel method based on an automatic graph-based segmentation approach applied to a 3-D polygonal mesh that operates on gray-scale 3-D TEE images starting from a user-defined initialization. Its application results in delineation of the narrowest portion of the regurgitant jet, corresponding to the 3-D ARO, the morphology of which can be quantified by shape descriptors. Additional aims were to determine the robustness of the proposed approach from the user settings and to compute its performance in comparison with the computed EROA, representing the standard analysis approach.

## METHODS

The proposed method operates on a systolic (*i.e.*, closed valve) frame and is summarized in Figure 1. The algorithm involves three steps: (i) a user-initialized segmentation stage (Fig. 1a) from which a 3-D surface (corresponding to a polygonal mesh) containing the regurgitant orifice and surrounding structures is semi-automatically computed; (ii) a completely automated procedure for segmentation of the 3-D ARO contour (Fig. 1b); and (iii) a quantification stage (Fig. 1c) in which several 2-D and 3-D morphological parameters are computed.

The rationale underlying this approach relies on the morphology of the regurgitant jet when the valve is closed: this jet starts in the left ventricle and gradually constricts until it reaches the ARO, from which it expands radially into the left atrium. In a 3-D TEE image, this regurgitant orifice corresponds to a continuous channel connecting the atrial and ventricular blood pools (Fig. 2, left). Accordingly, instead of detecting the tissue in the image (mitral leaflets or annulus), the method focuses on the 3-D segmentation of the void regions near the orifice, corresponding to the lower (almost black)-intensity voxels. This segmented region will contain the narrowest passage area of the regurgitant blood flow, corresponding by definition to the 3-D ARO. A detailed description of the proposed algorithm follows.

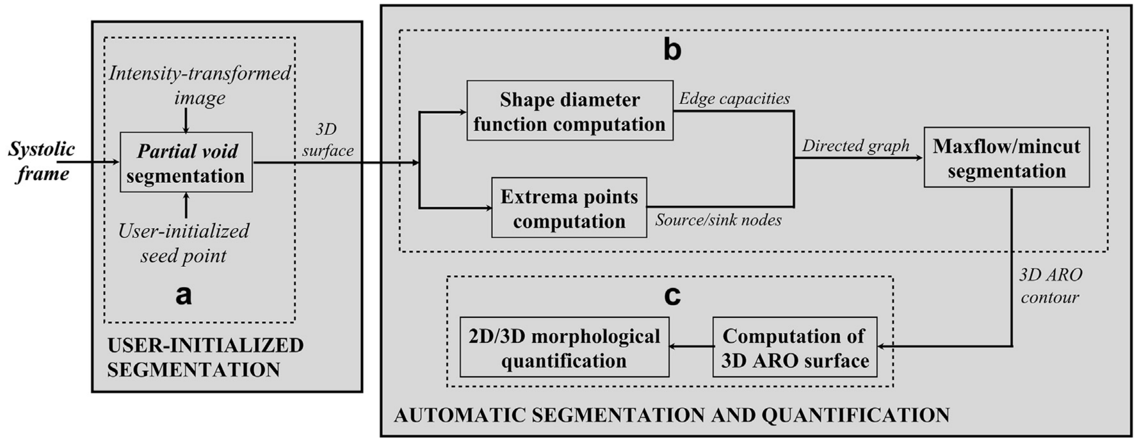


Fig. 1. Flowchart of the proposed algorithm for 3-D anatomic regurgitant orifice (ARO) segmentation and quantification. Starting from the manually selected systolic frame and a user-initialized segmentation (a), automated analysis is performed to obtain the 3-D ARO surface (b) and compute 2-D and 3-D morphological parameters of potential clinical interest (c).