The effective regurgitant orifice (ERO) area is estimated by dividing the RegV by the TVI of mitral regurgitation (MR) velocity recorded with continuous wave Doppler echocardiography:

\[
\text{ERO}_{\text{MR}} = \frac{\text{MV}_{\text{RegV}}}{\text{MR}_{\text{TVI}}}
\]

**Proximal Isovelocity Surface Area Method**

The effective regurgitant orifice and volume of mitral regurgitation are best obtained with the PISA method, which is based on the principle of conservation of flow and the continuity equation (58–61). Whereas the flow through a stenotic aortic valve is calculated from the LVOT in the continuity equation, the regurgitant flow through the mitral valve is calculated from PISA. As blood in the LV converges toward the mitral regurgitant orifice, blood flow velocity gradually increases and forms a series of hemispheric waves, and the velocity is the same for the surface of each wave (isovelocity) (Fig. 12-37). Color flow imaging can identify a PISA in the LV because the red-blue aliasing interface corresponds to the surface of the hemisphere whose flow velocity is the same as the aliasing velocity. Therefore, the flow rate at the surface of a hemispheric PISA is the product of the area of the hemisphere and the aliasing velocity. Aliasing velocity needs to be lowered to create a larger PISA (for flow away from the apical transducer) because the further the flow is from the regurgitant orifice, the slower the velocity. Aliasing velocity can be altered by downward shift of the zero baseline (in case of TTE imaging of mitral regurgitation) so that an optimal (hemispheric) PISA can be identified. The flow rate at PISA is equal to the flow rate across the regurgitant orifice:

Flow rate at PISA = Flow rate across regurgitant orifice

\[
2\pi r^2 \times \text{Aliasing velocity} = \text{ERO} \times \text{MR velocity}
\]

After ERO has been calculated, mitral RegV is calculated as:

\[
\text{MR RegV} = \text{ERO} \times \text{MR TVI}
\]

The stepwise method of obtaining the mitral regurgitation flow rate, effective regurgitant orifice area, and mitral regurgitant volume using the PISA method is as follows:

Step 1. Optimize color flow imaging of mitral regurgitation from an apical window (Fig. 12-38 and 12-39 A); PISA calculation may be possible from the parasternal long-axis view if the mitral regurgitant jet is eccentric and directed posteriorly.

Step 2. Expand the image of the regurgitant mitral valve by using the zoom or regional expansion selection mode (Fig. 12-38 and 12-39 B).

Step 3. Shift the color flow zero baseline downward to increase hemispheric PISA; the negative aliasing velocity is usually 20 to 40 cm/s (Fig. 12-38 B and 12-39 B); zero baseline shift of the color flow map is toward the direction of desired color flow jet; the baseline shift is upward (toward the transducer) if TEE is used.

Step 4. Use cine mode to scroll through several cardiac cycles to select the most satisfactory hemispheric PISA, which occurs at mid-systole.

Step 5. From a frame with an ideal PISA, measure the radius \(r\) (in cm) of the PISA at mid-systole (Fig. 12-38 B and 12-39 C) along the direction of the ultrasound beam.

Step 6. Measure the mitral regurgitation velocity with continuous wave Doppler to obtain the peak mitral regurgitation velocity (in cm/s) and TVI (in cm) (Fig. 12-39 C).

Step 7. Calculate mitral flow rate, effective regurgitant orifice, and mitral regurgitation volume, as described.

The effective regurgitant orifice and regurgitant volume go in parallel in determining the severity of mitral regurgitation.

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**Figure 12-37 A:** Diagram of proximal isovelocity surface area (PISA) (arrows) of mitral regurgitation. As blood flow converges toward the mitral regurgitant orifice, blood flow velocity increases gradually and forms multiple isovelocity hemispheric shells. The flow rate calculated at the surface of the hemisphere is equal to the flow rate going through the mitral regurgitant orifice. Ao, aorta; LA, left atrium; LV, left ventricle. **B:** Calculation and derivation of the effective regurgitant orifice (ERO) area of mitral regurgitation (MR) using the PISA method. R, PISA radius; V, velocity.