Geometry of the Proximal Isovelocity Surface Area of Mitral Regurgitation by Three-Dimensional Color Doppler Echocardiography: Difference Between Functional Mitral Regurgitation and Mitral Valve Prolapse

Cleveland Clinic
Cleveland, Ohio

Yoshiki Matsumura, Shota Fukuda, Hung Tran, Neil L. Greenberg, Deborah A. Agler, Nozomi Wada, Manatomo Toyono, James D. Thomas, and Takahiro Shiota

Background

Functional mitral regurgitation (FMR) is a common and important complication in patients with dilated cardiomyopathy, and it influences long-term prognosis and mortality (1). Prior investigators reported that the quantified degree of FMR defined by effective regurgitant orifice area (ERO) $\geq$0.2cm^2 was considered severe and associated with the mortality in patients with FMR (1), whereas in organic MR, ERO $\geq$0.4cm^2 was considered severe (2). The exact cause of this difference of the cut-off value remains to be elucidated.
The proximal isovelocity surface area (PISA) method has been established for determining ERO (3). The geometry of PISA is conventionally assumed to be a hemisphere in this method. However, PISA geometry of MR, particularly that of FMR, remains to be clarified. If the geometry of PISA of FMR is not a hemisphere, but a flattened shape, PISA method may underestimate the degree of FMR (4, 5). The recent advances of real-time three-dimensional echocardiography (RT3DE) and 3D color Doppler imaging techniques could reveal the 3D geometry of PISA in patients with FMR.

Objective

1) To investigate the 3D geometry of PISA in patients with FMR as opposed to MR in patients with mitral valve prolapse (MVP) by using RT3DE.
2) To test the hypothesis that the conventional PISA method underestimate ERO in patients with FMR.

Methods

Study Population:

18 patients with significant FMR and 14 patients with significant MR due to MVP (Regurgitant volume >45 ml)
• Functional MR was defined as significant MR with global left ventricular (LV) dilatation and dysfunction and without morphological abnormalities of the mitral apparatus.
• Exclusion Criteria: Permanent atrial fibrillation, Poor image quality of RT3DE

Echocardiographic Examination:

Vivid 7 (GE Medical Systems, Milwaukee, Wisconsin) in 14 (44%) patients
Sonos 7500 (Philips Medical Systems, Andover, Massachusetts) in 6 (19%) patients
iE-33 (Philips Medical Systems) in 12 (38%) patients

2D Echocardiography:

The average ERO was calculated as a ratio of the regurgitant volume to the time-velocity integral of regurgitant jet as follows: ERO by 2D quantitative Doppler method = (regurgitant volume) / (regurgitant time-velocity integral) = [(mitral stroke volume) – (aortic stroke volume)] / (regurgitant time-velocity integral).

Real-Time 3D Echocardiography with 3D Color Doppler Imaging:

Volumetric Image Acquisition (apical view):
Full volume mode: Volumetric images of the entire LV
Color 3D mode: 3D color Doppler images of the MR

3D Measurements of LV Volumes and Shape:
The end-diastolic volume, end-systolic volume, and ejection fraction by the computer software designed to semi-automatically detect the endocardial surface, and the sphericity index at end-diastole and end-systole.

3D Measurements of PISA Shape and ERO:
Three anteroposterior (AP) planes perpendicular to commissure-commissure (CC) plane were generated (***Fig. 1A***). After Doppler color aliasing velocity was decreased to an adequate range, the geometry of PISA was observed by using en-face color 3D images (***Fig. 1A***). The horizontal (parallel to the annular plane) length (l) of PISA was measured on CC plane (***Fig. 1B, CC plane***), and the vertical (to the annular plane) radius (r) of PISA was measured on the medial, central, and lateral AP plane (***Fig. 1B, AP plane M, C, and L***).
ERO was calculated by using the maximum vertical radius as follows: ERO by 3D PISA method = 2π×(maximum vertical radius)^2×(aliasing velocity) / (peak regurgitant velocity).

Fig. 1A

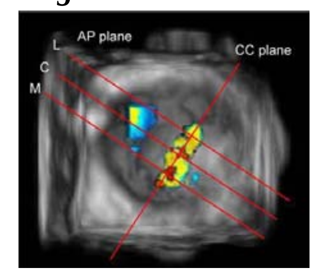
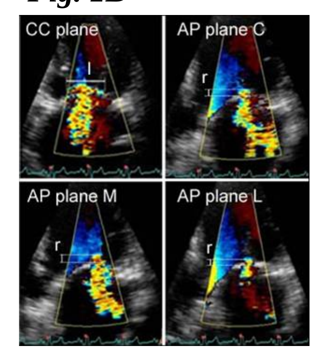


Fig. 1B



(M indicates medial plane; C, central plane; L, lateral plane.)

Results

Patients Characteristics:

	FMR (n=18)	MVP (n=14)	*P*
Age (years)	59±15	57±14	NS
Male (n)	12	10	NS
LV			
End-diastolic volume (ml)	318.7±59.2	194.1±30.9	<0.001
End-systolic volume (ml)	231.6±60.7	71.5±15.4	<0.001
Ejection Fraction (%)	28.2±7.4	63.0±5.9	<0.001
Sphericity at end-diastole	0.52±0.07	0.45±0.04	<0.01
Sphericity at end-systole	0.41±0.08	0.31±0.06	<0.005
MR			
Regurgitant volume (ml)	55.7±7.7	65.7±16.5	NS
Regurgitant fraction (%)	56.1±6.3	52.4±7.2	NS
ERO by 2D quantitative Doppler method (cm²)	0.40±0.12	0.45±0.18	NS

En-Face Color 3D Images:

An elongated and slightly curved PISA geometry along the entire leaflet coaptation line in all patients with FMR (***Fig. 2A***), while a rounder shape PISA appeared only in the lesion that the leaflet prolapsed in MVP (***Fig. 2B***).

Fig. 2A; FMR

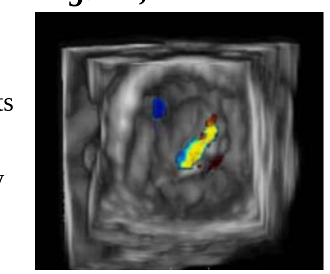
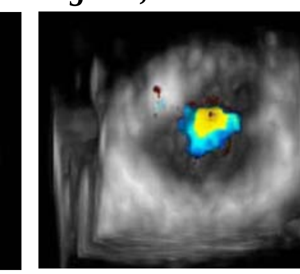


Fig. 2B; MVP



Geometric Measurements of PISA and ERO by 3D PISA Method:

	FMR (n=18)	MVP (n=14)	*P*
Horizontal length of PISA (cm)	2.2±0.4	1.1±0.3	<0.001
Maximum vertical radius of PISA (cm)	0.6±0.2	1.0±0.2	<0.001
MR flow rate with maximum radius (ml/sec.)	95.3±50.0	264.9±103.3	<0.001
ERO by 3D PISA method (cm²)	0.20±0.12	0.45±0.22	<0.001

ERO by 3D PISA method was well correlated with that by 2D quantitative Doppler method. However the 3D PISA method underestimated ERO by 24%, compared with the 2D quantitative Doppler method in FMR group (***Fig. 3A***), while in MVP group, the relation between the values by the two methods was close to the line of identity (***Fig. 3B***), indicating that the two methods provided almost identical values.

Fig. 3A; FMR

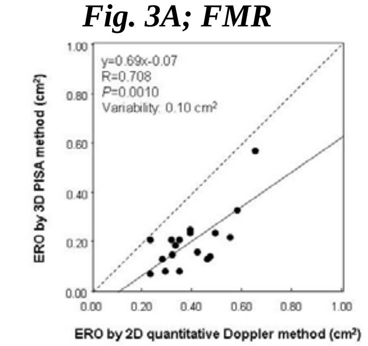
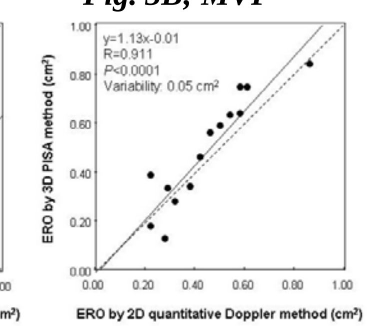


Fig. 3B; MVP



Conclusions

The geometry of PISA in FMR is elongated and slightly curved, distinctly different from the more focal pathology of MVP, leading to underestimation of ERO in FMR. Careful consideration of 3D geometry of PISA may be essential in evaluating of severity of FMR.

References

1. Grigioni F, et al. Ischemic mitral regurgitation: long-term outcome and prognostic implications with quantitative Doppler assessment. *Circulation.* 2001;103:1759-1764.
2. Dujardin KS, et al. Grading of mitral regurgitation by quantitative Doppler echocardiography: calibration by left ventricular angiography in routine clinical practice. *Circulation.* 1997;96:3409-3415.
3. Vandervoort PM, et al. Application of color Doppler flow mapping to calculate effective regurgitant orifice area. An in vitro study and initial clinical observations. *Circulation.* 1993;88:1150-1156.
4. Utsunomiya T, et al. Doppler color flow "proximal isovelocity surface area" method for estimating volume flow rate: effects of orifice shape and machine factors. *J Am Coll Cardiol.* 1991;17:1103-1111.
5. Iwakura K, et al. Comparison of orifice area by transthoracic three-dimensional Doppler echocardiography versus proximal isovelocity surface area (PISA) method for assessment of mitral regurgitation. *Am J Cardiol.* 2006;97:1630-1637.