PISA method for assessment of mitral regurgitation in children

Çocuklarda romatizmal mitral yetmezliğinin değerlendirilmesinde PISA yöntemi

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ABSTRACT

Objective: The purpose of this study was to determine the feasibility and significance of the proximal isovelocity surface area (PISA) method in children with rheumatic mitral regurgitation (MR).

Methods: Thirty-one children (mean age 12.3±3.1 years), with chronic MR, were evaluated by semiquantitative and quantitative Doppler, quantitative two-dimensional echocardiography and the PISA methods. Also, we compared the effective regurgitant orifice area, regurgitation volume and systolic left ventricular functions in mild-moderate and severe MR.

Results: There were no statistically significant differences in the regurgitant orifice area and regurgitant volume values obtained by the PISA method and the quantitative Doppler ($p>0.05$) but they were different from the same values obtained by two dimensional echocardiography ($p<0.05$). There were excellent correlations between the regurgitant orifice area, regurgitant volume and the radius of the proximal flow convergence hemisphere ($r=0.882$, $r=0.925$, $r=0.880$; $p<0.05$). We found a very good correlation between the regurgitant orifice area obtained by the PISA and left ventricular end-diastolic diameters, the ratio of the jet/left atrial area, grading with color Doppler imaging ($r=0.763$, $r=0.745$, $r=0.618$; $p<0.05$).

Conclusion: It is concluded that MR can be accurately predicted in children by using the PISA method as like as the Doppler method. *(Anadolu Kardiyol Derg 2005; 5: 167-71)*

Key words: The proximal isovelocity surface area, mitral regurgitation, childhood

ÖZET

Amaç: Romatizmal mitral yetmezliği (MY) olan çocuklarda proksimal izovelosite yüzey alanı (PISA) yönteminin uygulanabilirliğini araştırmak.

Yöntemler: Yaş ortalaması 12.3±3.1 yıl olan kronik izole romatizmal MY'li 31 çocuk (14 erkek, 17 kız) yarı kantitatif, kantitatif Doppler, kantitatif iki boyutlu ekokardiyografi ve PISA yöntemi ile MY'nin ağırlık derecesi açısından değerlendirildi. Ayrıca hafif-orta derece ve ağır MY grupları arasında regürjitan orifis alanı, regürjitan volüm, sistolik, diyastolik sol ventrikül fonksiyonları ve volüm yüklenmesini gösteren değişkenler açısından birbiri ile karşılaştırıldı.

Bulgular: Kantitatif Doppler yöntemi ve PISA ile elde edilen regürjitan orifis alanı ve regürjitan volüm sonuçları arasında istatistiksel anlamlı bir fark saptanmadı ($p>0.05$) fakat her iki yöntem ile ölçülen değerler iki boyutlu ekokardiyografi ile elde edilen değerlerden farklı bulundu ($p<0.05$). Regürjitan orifis alanı, regürjitan volüm ve PISA yarıçapı arasında mükemmel bir bağlantı saptandı ($r=0.882$, $r=0.925$, $r=0.880$; $p<0.05$). Proksimal izovelosite yüzey alanı yöntemi ile saptanan regürjitan orifis alanı, sol ventrikül diyastol sonu çapı, yetmezlik jeti alanı / sol atriyum alanı, renkli Doppler görüntüleme ile MY jetinin büyüklüğü arasında çok iyi bir bağlantı olduğu görüldü ($r=0.763$, $r=0.745$, $r=0.618$; $p<0.05$).

Sonuç: Çocuklarda MY değerlendirmesinde PISA metodu, Doppler yöntemi kadar kullanılabilecek bir yöntemdir. *(Anadolu Kardiyol Derg 2005; 5: 167-71)*

Anahtar kelimeler: Proksimal izovelosite yüzey alanı, mitral yetmezliği, çocukluk çağı

Introduction

The assessment of the severity of mitral regurgitation (MR) is one of the major goals of clinical cardiology. Its severity has a critical impact on clinical decision-making (1). The proximal isovelocity surface area (PISA) method is a new noninvasive technique for quantifying the severity of valvular regurgitation by echocardiography (2-8). There is no single precise method for calculation regurgitant orifice area (ROA) and regurgitant volume (RV). But they can be calculated clearly and independently of machine setting or orifice shape with the PISA method (1-8). Calculation of RV, ROA by quantitative Doppler, two-dimensional echocardiography, and the PISA technique are established methods to evaluate MR severity in adults. When applying PISA method to children, it should be noted that the RV and ROA are small (9) and the method requires the time to calculate. Thus, PISA has not been widely applied in routine clinical practice, especially in children. We therefore carried out this prospective study to determine the feasibility and significance of the PISA method in children with rheumatic MR.

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Anadolu Kardiyol Derg
2005; 5: 168-71

Methods

Study patients

At the Pediatric Cardiology Clinics of the Meram Medical Faculty, Konya in 2002, we prospectively scanned 31 patients who fulfilled the following inclusion criteria: 1) the presence of more than trace MR in the standard color Doppler evaluation of regurgitant jet size, 2) the presence of a recognizable proximal flow convergence region on the ventricular side of the mitral valve in the four-chamber apical view by color Doppler imaging, 3) the absence of concomitant lesions (aortic valve insufficiency, valvular stenosis, or prostheses at the aortic or mitral level and intracardiac shunt flows) that would interfere with the study, 4) the availability of echocardiographic images and Doppler traces of suitable quality for quantification.

The PISA, quantitative Doppler and two-dimensional echocardiographic values were measured and compared each other. Additionally, semiquantitative Doppler techniques, systolic functions and PISA measures were compared with regarding MR severity. First- and second- degrees of MR wereclassified as mild-moderate and third and fourth degrees - as severe MR.

Echocardiographic studies

All patients were examined in a decubitus or lateral decubitus position from the apical view by the same experienced investigator with Hewlett-Packard Sonos 1000 instruments with 2.5 and 3.5 MHz transducers. Each echocardiographic and Doppler measurement was obtained in three to five different cardiac cycles, and the average was used in subsequent analysis. Images were additionally recorded on videotape. An electrocardiogram was recorded simultaneously.

Quantitative Doppler and quantitative two-dimensional echocardiography method

Annular cross-sectional area and time-velocity integral measurements were used to calculate the mitral and aortic stroke volumes by quantitative Doppler and two-dimensional echocardiography, as previously described (10). Next, the quantitative Doppler ROA and RV were calculated as follows: RV(Doppler) = (mitral-aortic) stroke volume; $ROA_{(Doppler)} = RV_{(Doppler)}$ / mitral regurgitant time-velocity integral; and quantitative two-dimensional, ROA and RV calculated like this: $RV_{(Two\text{-}dimensional)}$ = (left ventricle-aortic) stroke volume; $ROA_{(Two\text{-}dimensional)} = RV_{(Two\text{-}dimensional)}$ / mitral regurgitant time-velocity integral.

Proximal isovelocity area method

This method used the proximal flow convergence and was performed as previously described (2-9,11); $RV_{(PISA)} = 2 \times \pi \times r^2 \times Vr$, where r is radius of proximal flow convergence and Vr is aliasing velocity; $ROA_{(PISA)} = RV_{(PISA)}$ / mitral regurgitant time-velocity integral.

Semiquantitative Doppler and other measurements

The MR jet was graded as first-, second-, third- and fourth-degree by color Doppler imaging. The regurgitant jet area within the left atrium was measured by planimetry from the frame with the maximal jet area during systole. The jet area was expressed as an absolute value and as a percentage of the left atrial area. The jet length was defined as the maximal distance of the regurgitant signals from the mitral valve orifice. The left ventricular volumes were calculated as recommended by the American Society of Echocardiography using modified Simpson's rule (12). Cardiac index was calculated by multiplying the heart rate by the stroke volume and indexed to body surface area.

Statistical analysis

All results were expressed as mean ± SD. The statistical significance of differences between groups was tested with paired t-test. Linear regression analysis was used to examine the relation between the RV, ROA ad other variables. Pearson's correlation method was used to assess the association between the PISA and other methods. A p value <0.05 was considered significant. The analyses were performed using the Statistical Package for the Social Sciences 11.0 (SPSS, Inc., Chicago, IL, USA) for Windows software.

Results

Patient characteristics

The 31 patients were 17 girls (54.8%), 14 boys (45.2%), with mean age of 12.3±3.1 (7-17) years, weighing 42±16.2 (19-81) kg and body surface area of 1.2±0.3 (0.7-1.9) m^2. We had four groups patients with visual grading of first- (n=9, 29%), second- (n=8, 25.8%), third- (n=11, 35.5%) and fourth – (n=3, 9.7%) degrees of MR. The etiology of regurgitation was rheumatic heart disease and all patients had sinus rhythm.

Comparison between quantitative Doppler, two-dimensional echocardiography, and PISA methods

Nyquist velocity and the radius of the proximal convergence region were 29.8±5.4 (22-42) cm/s and 0.65±0.28 (0.24-1.34) cm. The ROA was 23.2±18.2 (2.7-91.3) mm^2 by PISA method, 22±27.3 (0.8-144.4) mm^2 by quantitative Doppler and 16.3±18.4 (0.9-88.6) mm^2 by quantitative two-dimensional echocardiography. The RV was 20.8±17.3 (2.4-70.5) ml by PISA, 18.9±23.7 (1.2-111.4) ml by quantitative Doppler and 14.4±16.6 (1.1-68.4) ml by two-dimensional echocardiography. There were no statistically significant differences between $ROA_{(PISA)}$, $RV_{(PISA)}$ and $ROA_{(Doppler)}$, $RV_{(Doppler)}$ (p>0.05). But there were statistically significant differences between $ROA_{(PISA)}$ - $ROA_{(Two\text{-}dimensional)}$, $ROA_{(Doppler)}$ - $ROA_{(Two\text{-}dimensional)}$, $RV_{(PISA)}$ - $RV_{(Two\text{-}dimensional)}$, and $RV_{(Doppler)}$ - $RV_{(Two\text{-}dimensional)}$ (p<0.05) (Table 1).

Significant correlations between the radius of the proximal convergence region, $RV_{(PISA)}$, $ROA_{(PISA)}$, $RV_{(Doppler)}$, $ROA_{(Doppler)}$ (r=0.882, r=0.925, r=0.880, r=0.832, r=0.798; p<0.05) were found. There were good correlations between color Doppler regurgitation jet imaging and $ROA_{(PISA)}$, $RV_{(PISA)}$; between regurgitation jet length and all the PISA measurements; between the ratio of regurgitant jet area/left atrium area and the radius of the proximal convergence region, $ROA_{(PISA)}$; between left ventricle end-diastolic diameter and the radius of the proximal convergence region, $RV_{(PISA)}$ (Table 2, Fig. 1-4).

Comparison of regurgitation severity

The jet length was 2.9±0.8 cm in mild-moderate and 4±1.4 cm in severe MR. The ratio of regurgitant jet area/left atrium area was 24.8±13% in mild-moderate, 42±17.8% in severe regurgitation. The ROA(PISA) and RV(PISA) were 13.2±10.5 mm^2, 10.9±11.2 ml in mild-moderate, 35.2±18.6 mm2, 32.7±16 ml in severe. The differences between groups were statistically significant (p<0.05).

There were statistically significant differences between groups in parameters of systolic function (p<0.05) (Table 3). So,ejection fraction was 60.7±2% in mild-moderate MR and 63.6±5.3% in severe MR. Fractional shortening was 35.2±3.3% in mild-moderate MR and 37.8±5.5% in severe MR. Also stroke volume, cardiac output and cardiac index were 71.1±19.8 ml, 5.7±1.6 l/min, 4.5±1 l/min/m^2 in mild-moderate and 89.6±37.5 ml, 8.1±2.3 l/min, 6.4±1.6 l/min/m^2 in severe MR, respectively.

Discussion

In patients with MR, knowing the severity of the regurgitation is important for determining the timing of the mitral valve operation. Left ventriculography was the standard approach for determining the severity of MR, but angiography is invasive and has inherent risks (8). Semiquantitative methods are used the length or area of the jet or the ratio of areas of jet and left atrium, but they are hindered by important limitations. The jet area is not linearly or easily related to measured flow volume (8,13) and it is markedly affected by changes in driving pressure, orifice area, chamber size, and gain settings (13).

Table 1. Echocardiographic findings of patients

Variables		Mean±SD (range)	p
PISA	Nyquist velocity (cm/s)	29.8±5.4 (22-42)	
	The radius of PISA (cm)	0.65±0.28 (0.24-1.34)	
	ROA (mm^2)	23.2±18.2 (2.7-91.3)	*
	RV (ml)	20.8±17.3 (2.4-70.5)	*
Quantitative	ROA (mm^2)	22±27.3 (0.8-144.4)	†
Doppler	RV (ml)	18.9±23.7 (1.2-111.4)	†
Quantitative	ROA (mm^2)	16.3±18.4 (0.9-88.6)	†
Two-dimensional	RV (ml)	14.4±16.6 (1.1-68.4)	†
Others	Regurgitant jet length (cm)	3.4±1.2 (1.5-6.44)	
	The ratio of jet/left atrial area (%)	32.6±17.4 (11-73)	
	Regurgitant velocity (cm/s)	402.0±95.9 (246-576)	
	Regurgitant time-velocity integral (cm)	87.5±33.7 (36-157)	

PISA= the proximal isovelocity surface area, ROA=regurgitant orifice area, RV=regurgitant volume, *$p>0.05$ in $ROA_{(PISA)}$-$ROA_{(Doppler)}$ and in $RV_{(PISA)}$-$RV_{(Doppler)}$, †$p<0.05$ in quantitative two-dimensional and ROA-$RV_{(PISA-Doppler)}$.

Table 2. Correlations between values from the proximal isovelocity surface area method and quantitative-semiquantitative Doppler echocardiography

Parameters	The radius of PISA		$ROA_{(PISA)}$		$RV_{(PISA)}$	
	r	p	r	p	r	p
Regurgitant orifice area (Doppler) (mm^2)	0.678	*0.000	0.832	*0.000	0.696	*0.000
Regurgitant volume (Doppler) (ml)	0.765	*0.000	0.802	*0.000	0.798	*0.000
Regurgitant orifice area (PISA) (mm^2)	0.882	*0.000	—	—	0.880	*0.000
Regurgitant volume (PISA) (ml)	0.925	*0.000	—	—	—	—
Grading with color Doppler imaging	0.755	*0.000	0.618	*0.000	0.646	*0.000
Regurgitant velocity (cm/s)	0.405	*0.024	0.063	0.737	0.363	*0.045
Regurgitant jet length (cm)	0.560	*0.001	0.543	*0.000	0.644	*0.000
The ratio jet/left atrial area (%)	0.643	*0.000	0.745	*0.000	0.590	*0.000
Cardiac index (L/min/m^2)	0.445	*0.012	0.501	*0.004	0.446	*0.012
Left ventricle end-diastolic diameter, mm	0.669	*0.000	0.763	*0.000	0.743	*0.000
Left ventricle end-systolic diameter, mm	0.309	0.109	0.403	*0.034	0.383	*0.044

PISA= the proximal isovelocity surface area, ROA=regurgitant orifice area, RV=regurgitant volume, * =statistically significant

Table 3. Comparisons by regurgitation severity

Variables	Mild-moderate regurgitation mean±SD (range)	Severe regurgitation mean±SD (range)	p
ROA (PISA) (mm2)	13.2±10.5 (2.7-38.1)	35.2±18.6 (17.4-91.3)	0.001
RV (PISA) (ml)	10.9±11.2 (2.4-43.7)	32.7±16.0 (8.2-70.5)	0.002
Regurgitant velocity (cm/s)	376.8±102.0 (246-560)	432.7±81.1 (280-576)	0.000
Regurgitant jet length (cm)	2.9±0.8 (1.5-4.4)	4.0±1.4 (2.3-6.44)	0.000
The ratio jet/left atrial area (%)	24.8±13.0 (11-66)	42.0±17.8 (19-73)	0.001
Ejection fraction (%)	60.7±2.0 (58-66.3)	63.6±5.3 (53-72.3)	0.003
Fractional shortening (%)	35.2±3.3 (30.8-42)	37.8±5.5 (26.8-44.8)	0.000
Stroke volume (ml)	71.1±19.8 (42-120)	89.6±37.5 (50.8-204)	0.002
Cardiac output (l/min)	5.7±1.6 (4.2-10.6)	8.1±2.3 (4.5-12.8)	0.000
Cardiac index (l/min/m2)	4.5±1.0 (2.8-6.5)	6.4±1.6 (4.3-9.1)	0.004

ROA=regurgitant orifice area, RV=regurgitant volume

Quantitative echocardiographic measures include calculation of RV, regurgitant fraction and ROA by two-dimensional and Doppler echocardiography and PISA method, respectively (5,6,8,9,11). The effective ROA is a measure of the severity of the regurgitant lesion (14). It is also a major determinant of the enlargement of the left ventricle and left atrium in mitral regurgitation and provides additional information compared with RV and fraction (4,7). Thus, effective ROA is a fundamental quantitative measure of MR. The PISA method is being developed to improve quantification of regurgitant flow. This method allows us to calculate RV and ROA, based on the principle of conservation of mass in the proximal flow field (2-9,11,13, 15-19).

There is a problem when applying this method to children that RV and ROA is small because of the small heart size. Another problem is that Schwammenthal (5) and Enriquez-Sarano et al (18) reported that differences in the dynamic change in ROA

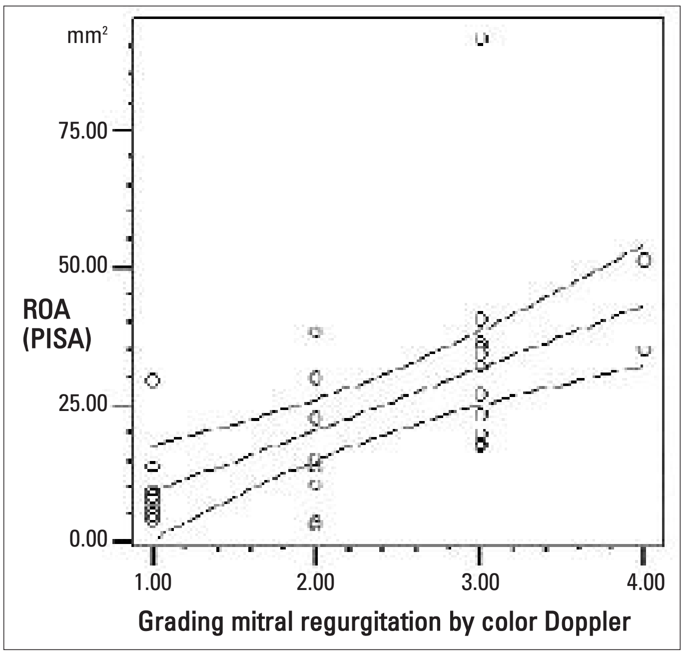


Figure 1. Correlations between the effective regurgitant orifice area obtained by the proximal isovelocity surface area method and grading mitral regurgitation by color Doppler imaging. ROA=regurgitant orifice area, PISA=proximal isovelocity surface area

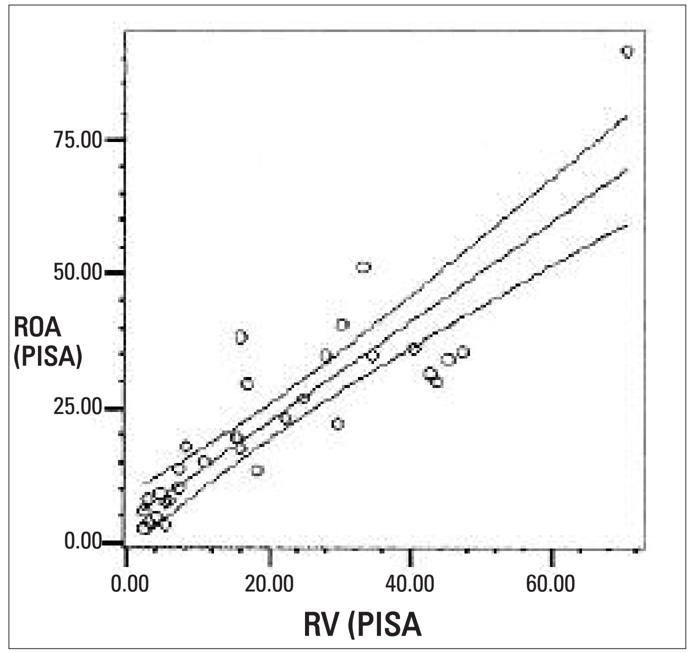
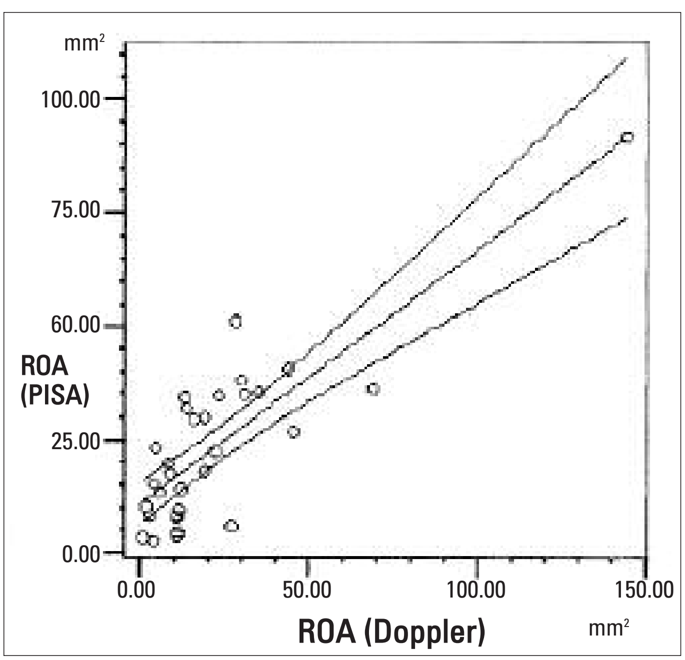


Figure 4. Correlations between the effective regurgitant orifice area and regurgitant volume obtained by the proximal isovelocity surface area method. ROA=regurgitant orifice area, PISA=proximal isovelocity surface area, RV=regurgitant volume, circles=patients, lines=regression line in middle and 95% confidence interval the others)



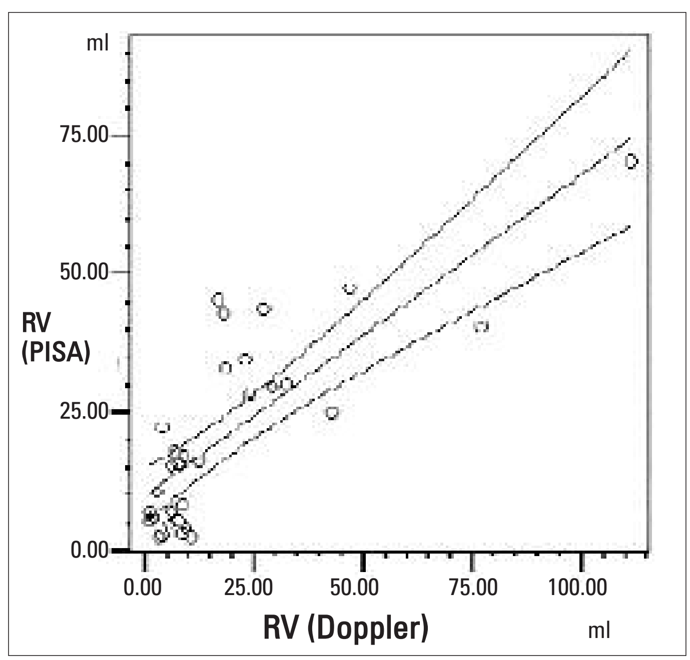


Figure 2 and 3. Correlations between the effective regurgitant orifice area and regurgitant volume obtained by the proximal isovelocity surface area method and by quantitative Doppler echocardiography. ROA=regurgitant orifice area, PISA=proximal isovelocity surface area, RV=regurgitant volume

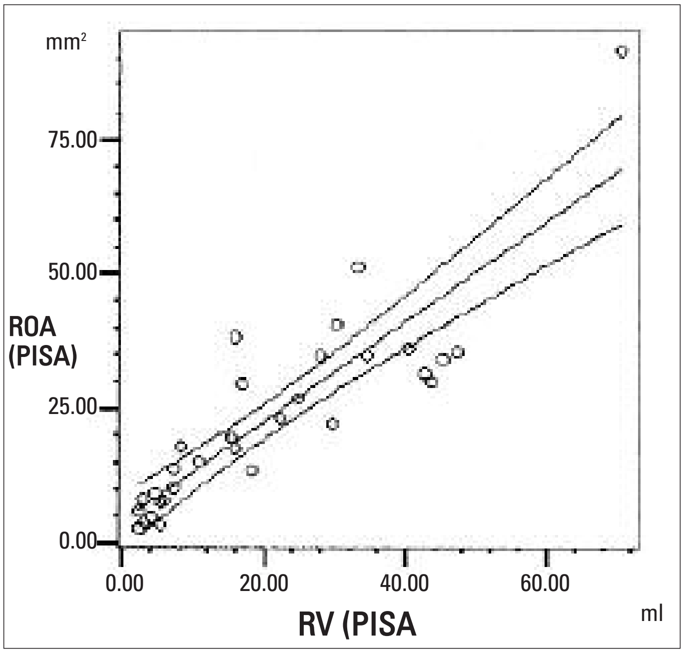


Figure 4. Correlations between the effective regurgitant orifice area and regurgitant volume obtained by the proximal isovelocity surface area method. ROA=regurgitant orifice area, PISA=proximal isovelocity surface area, RV=regurgitant volume, circles=patients, lines=regression line in middle and 95% confidence interval the others)

are related to etiologic factors of regurgitation. So, we only applied this method in children with rheumatic heart disease in the study.

Several studies have shown good correlations of the PISA method with angiographic findings and with Doppler methods (3,7,9,15,16). This method has been shown to have advantages over previous color Doppler flow methods in estimating volume flow rate because its results appear to be relatively insensitive to differences in machine factors and orifice shapes (16). In the present study, we did not find statistically difference between PISA and quantitative Doppler echocardiography in childhood, but there were significant correlations with each other. Enriquez-Sarano et al. (18) used a quantitative Doppler method as the reference method for the quantification of MR in adults. Obviously, assessment of severity of MR by the PISA methods may be accepted noninvasive quantitative parameters in children. Also, the PISA method is reliably differentiated between mild-moderate to severe MR in patients at the childhood.

Surprisingly, we found statistically significant differences between PISA and two-dimensional and also between Doppler and two-dimensional echocardiography measures. They may be due to technical limitations regarding calculation of the left ventricular volumes by the modified Simpson formulas by two-dimensional echocardiography.

The differentiation of mild-moderate to severe MR was possible by means of the jet area, jet length and the ratio of areas of jet and left atrium and PISA methods. This is in contrast to data from adults with MR patients. Bargiggia (2) and Grossman (19) reported that the flow convergence method was clearly superior for semiquantification approaches. Our results may be explained by homogenous patient characteristics because of same nature underlying etiologic disorder.

The statistically different systolic function parameters between mild-moderate and severe MR could be explained by compensatory factors and use inotropic agents by some patients.

In conclusion, the proximal flow convergence method was a suitable method for the quantification of MR in childhood. The effective ROA is an important and clinically significant index of the severity of regurgitation. The PISA methods as Doppler echocardiography can be easily applied in childhood. First and second degree MR could be reliably distinguished from third and fourth degree by the PISA, and quantitative and semiquantitative Doppler echocardiography.

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