# Non-invasive evaluation of aortic regurgitation by Doppler echocardiography in children: comparison with contrast angiography

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**SUMMARY: Alehan D, Elshershari H, Bilgiç A. Non-invasive evaluation of aortic regurgitation by Doppler echocardiography in children: comparison with contrast angiography. Turk J Pediatr 2003; 45: 15-20.**

**Doppler indexes have been used successfully to determine the severity of aortic regurgitation (AR) in adults but have not been evaluated in children. To determine the accuracy of pulsed, color, and continuous-wave (CW) Doppler echocardiographic indexes in assessing the degree of AR in children, the correlation between the non-invasive measurements and angiographic grading of the regurgitant flow (1+ to 4+) was examined in 14 children (mean age 11±3 years) with chronic AR.**

**Forward and reverse flows in the aortic arch were evaluated from the suprasternal notch using pulsed Doppler. Aortic time-velocity integrals (TVI) were measured during systole (forward flow) and diastole (reverse flow), and the ratio of reverse to forward TVI (%) was calculated. Doppler color flow mapping was used to detect and assess the severity of AR (which appears as mosaic turbulent signals extending in the left ventricular outflow tract during diastole) by using four color Doppler grades of severity. The envelope of the flow velocity pattern in diastole was recorded from the CW Doppler signal of AR with the transducer in the lower sternal border to determine the peak flow velocity and deceleration slope (α) indexes.**

**The ratio of reverse to forward aortic TVI and color flow mapping grading showed strong correlation with angiographic grade (r=0.92 and r=0.86, respectively) but AR slope (α) and peak flow velocity did not correlate well with the angiographic grade (r= -0.039 and r=0.74, respectively). We concluded that the severity of AR in children as determined by angiographic grading can be estimated with reasonable accuracy by noninvasive technique based on color and pulsed wave Doppler. Use of these indexes may obviate the need for angiography to detect the severity of AR in children.**

***Key words: aortic regurgitation, echocardiography, children.***

Aortic regurgitation (AR) produces left ventricular volume overload that may result in left ventricular dysfunction[1]. The appropriate timing of aortic valve replacement for aortic valve regurgitation is partially based on the development of symptoms. Valve replacement should be considered in the asymptomatic patient with left ventricular dilatation or decreased left ventricular systolic function[2]. Although grading of the regurgitant flow has traditionally been based on contrast angiography, its invasive nature makes it impractical for frequent serial examinations. Therefore, a reliable measurement of the magnitude of regurgitation as well as assessment of left ventricular function are necessary to determine the need and timing of valve replacement. Doppler echocardiography is a well established method for detecting AR; pulsed Doppler, continuous wave (CW) Doppler, and color Doppler have all been used as noninvasive means of evaluating the severity of AR in adults[2-12]. These studies have shown that the ratio of reverse to forward time-velocity integrals in the aorta measured using pulsed Doppler; the slope (deceleration rate) of the AR measured by CW Doppler signal; the maximum length of the color Doppler AR jet extending into the left ventricular cavity, and the width (diameter) of the AR color jet in the left ventricular outflow tract, all correlate with the severity of AR. To the best of our knowledge, these Doppler indexes have not been systematically evaluated in children.

This study evaluates the accuracy of pulsed, color and CW Doppler indices in determining the severity of AR in children by comparing the results with contrast angiography. We also examined the enfluence of concomitant aortic stenosis on the validity of Doppler echocardiography in evaluating AR.

## Material and Methods

The study population consisted of 14 children (12 boys, 2 girls, mean age 11±3 years) with chronic AR. All patients underwent diagnostic cardiac catheterization, and the presence of AR was confirmed by aortic root angiography. All patients had combined aortic stenosis and regurgitation, and peak aortic pressure gradients were <25 mmHg in 2, between 25-50 mmHg in 11 and >50 mmHg in 1 patient. Doppler examinations were performed 24 hours before cardiac catheterization in six patients, and within one week in the remainder, who had an obviously steady clinical condition. All patients were in sinus rhythm.

### *Echocardiographic Examination*

Standard 2-dimensional, M-mode, and Doppler echocardiograms were performed using Toshiba sonolayer SSH-60A Doppler echocardiograph equipped with 2.5, 3.75 and 5 MHz phased-array transducers. Forward and reverse flows in the aortic arch were evaluated from the suprasternal notch using pulsed Doppler (Fig. 1). Aortic time-velocity integrals (TVI) were measured during systole (forward flow) and diastole (reverse flow) and the ratio of reverse to forward TVI (%) was calculated[5].

From the parasternal long-axis view, Doppler color flow mapping was used to detect and assess the severity of AR, which appears as mosaic turbulent signals extending in the left ventricular outflow tract during diastole, using four color Doppler grades of severity. The envelope of the flow velocity pattern in diastole was recorded from the CW Doppler signal of AR with the transducer in the lower sternal border to determine the peak flow velocity (Vmax), half-time index ($t_{1/2}$) and deceleration slope ($\alpha$) indexes (Fig. 2). Measurements were made in triplicate and averaged by a cardiologist unaware of the angiographic results.

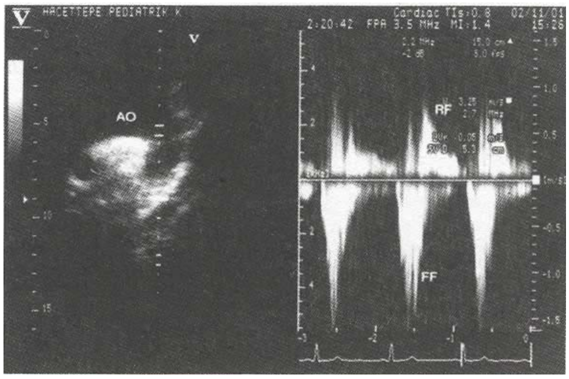


**Fig. 1.** Pulsed Doppler record of the aortic arch in aortic regurgitation. The signal of the systolic flow (FF, directed away from the transducer) and the signal of the diastolic flow (RF), directed toward the transducer) are shown. Two-dimensional view is obtained within the bend between the horizontal and descending segments of the arch.

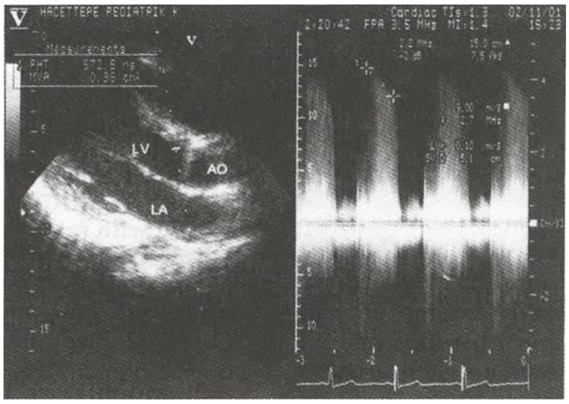


**Fig. 2.** Continuous-wave Doppler recording of aortic regurgitant flow in the left ventricular outflow tract.

### *Catheterization and Angiography*

All patients underwent biplane aortic angiography with injection of 1 ml/kg contrast material in 45° right and left anterior oblique projections through a size-appropriate pig-tail catheter positioned above the aortic valve. The degree of AR was graded independently from the echocardiographic findings by the method of Grossman[13] as follows:

Grade I: faint opacification of part of the left ventricle which clears with each systole;

Grade II: opacification of the left ventricle to a degree less than that in the aorta;

Grade III: opacification of the left ventricle equal to that of the aorta;

Grade IV: complete dense opacification of the left ventricle in one beat with a constant density greater than that in the aorta.

*Statistical Methods*

All values were expressed as mean±SD. Spearman's rank correlation coefficient was calculated to study the agreement between Doppler and catheterization variables. Statistical significance was inferred when p was <0.001.

## Results

In the angiographic assessment of AR, complete agreement occurred for 11 of 14 patients (79%) and differed by only 1 grade in the remaining three (21%) in whom AR was visualized by color Doppler examination. In the study group, five cases had 1+ or 2+ AR according to angiography (2 cases, 1+; 3 cases, 2+) and nine had 3+ or 4+ (7 cases, 3+; 2 cases, 4+) (Table I).

Pulsed Doppler was used to measure the ratio of reverse to forward TVI in the aortic arch (which also corresponds to the ratio of diastolic to systolic areas). The individual results in our study group are presented in Table I. Mean TVI ratio was 18% for grade I, 27% for grade II, 49.5% for Grade III and 77% for grade IV aortic regurgitation.

All the patients had AR by color flow mapping and these findings were confirmed by aortic angiography (Table I). The jet of AR was directed away from the aortic valve and consisted of mosaic turbulent signals of red, blue and green in the left ventricular outflow tract during diastole. Aortic stenosis did not interfere with the diagnosis of AR, because the regurgitant jet could be clearly seen in early diastole during isovolumic relaxation in the parasternal long-axis view in all cases.

The aortic regurgitant flow velocity patterns were successfully recorded in the left ventricular outflow tract with CW Doppler echocardiography. The pattern of aortic regurgitant flow was characterized by a rapid rise in flow velocity to a peak level just after the aortic valve closure, followed in turn by a slow linear deceleration until the next aortic valve opening. The mean diastolic peak flow velocity of the study group was 2.2±0.85 m/sec (range: 1.1 to 3.69 m/sec). The deceleration of the aortic regurgitant flow velocity (α) and the half-time index ($t_{1/2}$) were 3.56±1.68 m/sec$^2$ (range: 1.1 to 6 m/sec$^2$) and 248±58.39 msec (range: 144 to 362 msec), respectively.

**Table I.** Echocardiographic and Angiographic Evaluation of AR in the Study Group

| Case no. | $V_{max}$ | ∝ | $T_{1/2}$ | FTVI | RTVI | TVI (%) | Color Doppler (grade) | Aortography (grade) |
|---|---|---|---|---|---|---|---|---|
| 1 | 2.23 | 3 | 298 | 0.25 | 0.16 | 64 | III | III |
| 2 | 3.22 | 3.3 | 362 | 0.33 | 0.16 | 48 | III | III |
| 3 | 2.81 | 2.7 | 325 | 0.33 | 0.11 | 33 | II | II |
| 4 | 2.83 | 5.2 | 160 | 0.23 | 0.12 | 52 | III | III |
| 5 | 1.41 | 1.7 | 234 | 0.29 | 0.09 | 31 | III | II |
| 6 | 2.37 | 2.5 | 288 | 0.26 | 0.1 | 38 | III | III |
| 7 | 1.64 | 5.6 | 264 | 0.25 | 0.13 | 52 | III | III |
| 8 | 1.2 | 1.1 | 230 | 0.33 | 0.03 | 9 | I | I |
| 9 | 2.7 | 6 | 258 | 0.26 | 0.1 | 38 | III | III |
| 10 | 1.45 | 4 | 144 | 0.17 | 0.03 | 17 | I | II |
| 11 | 1.1 | 1.3 | 233 | 0.18 | 0.05 | 27 | I | I |
| 12 | 1.26 | 1.1 | 232 | 0.18 | 0.1 | 55 | III | III |
| 13 | 3.69 | 5.4 | 226 | 0.22 | 0.16 | 72 | IV | IV |
| 14 | 3 | 4.5 | 218 | 0.28 | 0.23 | 82 | III | IV |

$V_{max}$ : peak flow velocity (m/sec).
∝ : deceleration (m/sec$^2$).
$T_{1/2}$ : half-time index (msec).
FTVI : forward flow time-velocity integral (m).
RTVI : reverse flow time-velocity integral (m).
AR : aortic regurgitation.

Standard 2-dimensional, M-mode echocardiographic examinations of left ventricular dimension and systolic function of these patients were within normal range.

*Comparison of Indexed Doppler Measurements*

All Doppler indexes except CW Doppler slope correlated (P<0.001) with the angiographic AR grade (Table II). Correlation coefficients showing the relation between various Doppler measurements and the angiographic grade of AR are shown in Table II. The deceleration of the aortic regurgitant flow velocity (α) had no correlation with the angiographic grading of AR (r=-.39, p>0.001). The best correlations were found for the ratio of reverse to forward aortic TVI (r=0.92) and color flow mapping grading (r=0.86) (Fig. 3 and 4).

**Table II.** Correlation of Echocardiographic Indexes with Angiographic Grading of Aortic Regurgitation

| Doppler measurement | $r_s$ | P value |
|---|---|---|
| Ratio rev/fwd TVI in aortic arch | 0.92 | 0.000 |
| Color flow mapping | 0.86 | 0.000 |
| Peak flow velocity (Vmax) | 0.74 | 0.002 |
| Aortic regurgitation slope (α) | -0.039 | 0.908 |

rev : reverse.
fwd : forward.
α : deceleration (m/sec$^2$).
TVI : time-velocity integral.
$r_s$ : Spearman's rank correlation coefficients.

## Discussion

Quantification of regurgitant flow by Doppler echocardiography has been more problematic than establishment of the diagnosis. Therefore, a number of Doppler methods have been proposed for the assessment of AR in adults[3-12]. Clinicians routinely use several methods to determine the severity of AR. A reliable measurement of the magnitude of regurgitation is necessary because even mild AR may increase in severity, and many patients with chronic AR eventually require surgery either for symptoms, left ventricular dysfunction, or both[14]. Noninvasive quantification of the magnitude of the regurgitation would improve the assessment of these patients and could provide important additional data regarding the prognosis. In this study, several Doppler indexes were examined to evaluate their accuracy in determining the severity of AR in children. These indexes compared favorably with contrast angiographic grading of the lesion, with the pulsed wave and color Doppler methods tending to be the most accurate.

Different color Doppler methods have been applied for grading the severity of AR according to the length, width and area of the regurgitant jet[19-20]. The method used in this study was based on the approach proposed by Perry et al.[3], and considered the width of the AR jet relative to the size of the left ventricular outflow tract in the long-axis view. Thus, it was possible to detect the AR jet close to its origin and to get an acceptable color flow from the long-axis view. These investigators found that the width of the jet at its origin relative to the width of the left ventricular outflow tract was the best predictor of the angiographic grade of the regurgitation[3]. Our findings were also similar, and we found a good correlation (r: 0.86) between color grade and angiographic grade. The grading of AR can be influenced by the presence of other valve lesions. Our patients had AR combined with aortic valve stenosis of variable severity. The

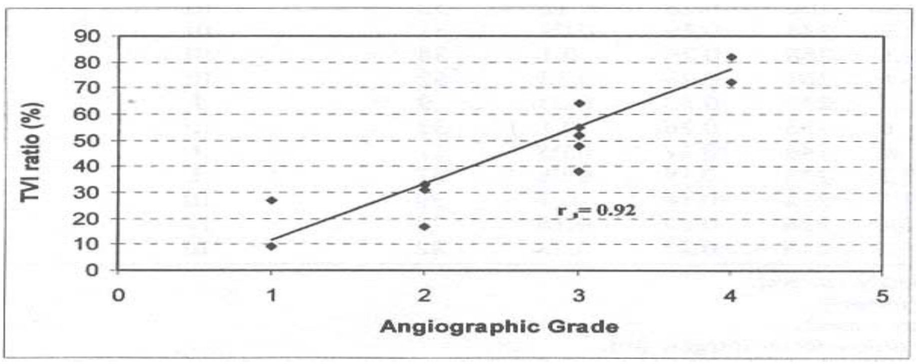


**Fig. 3.** Time-velocity integral (TVI) ratio in the aortic arch compared with angiographic grade of aortic regurgitation.

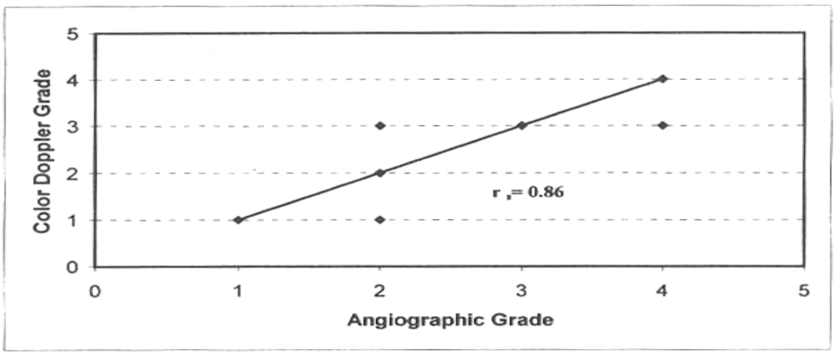


**Fig. 4.** Color Doppler results compared with angiographic grade of aortic regurgitation.

presence of additional aortic stenosis did not prevent us from predicting the grading of AR as confirmed by angiography. Our results were in accordance with the studies in which color Doppler was found to be reliable for AR grading in patients with combined aortic lesions.

In our study we have shown that the TVI of the retrograde diastolic flow signals obtained by pulsed Doppler technique increases with increasing severity of the valvular regurgitation. The ratio of the TVI of the reverse flow to that of the forward flow has correlated well with angiographic grading of the amount of aortic regurgitation (r: 0.92). The degree of AR that we determined with pulsed Doppler was not affected by the presence of valvular aortic stenosis. Ciobanu et al.[9] had also found the grading of AR with pulsed Doppler to be unaffected by associated aortic stenosis. Other authors, such as Diebold et al.[17], reported problems in grading AR in the presence of aortic stenosis with conventional Doppler methods. They recorded the aortic arch blood flow from the suprasternal notch by pulsed wave Doppler. Boughner[6] used the descending thoracic aorta flow velocity signals to calculate the ratio of the reverse to the forward flow areas, and parallel to our results, found a good correlation between the ratio and regurgitant fraction measured at catheterization.

The deceleration rate (∝) can be measured from the CW Doppler recording of the aortic regurgitation jet as the slope of a line drawn between the peak velocity and the velocity at end-diastole. This slope, which reflects the rate of decline of the diastolic pressure difference between the aorta and left ventricle, correlates in adult patients with the severity of the regurgitation. However, in our study, in contrast to previous studies in adults, the slope of the CW Doppler AR tracing did not correlate with angiographic AR severity in children. Possible reasons for this include: 1) the dependence of slope and pressure half-time index on heart rate, with faster and more variable heart rates found in children than adults; 2) the dependence of slope on systemic vascular resistance (afterload); or 3) the age dependence of aortic and ventricular compliance[18]. Furthermore, the velocity decay slope of the regurgitant signal seems to be more reliable in the absence of factors that might affect left ventricular function, such as concomitant aortic stenosis. Wilkenshoff et al.[19] found that the degree of velocity decay correlated to a lesser degree in adult patients with combined aortic lesions than in those with pure AR. Therefore, when CW Doppler indexes are used to assess the severity of aortic regurgitation, care must be taken to consider other factors that might be affecting the indexes.

Semiquantitative evaluation of AR by angiography is a currently accepted standard method for grading the severity of a regurgitant lesion. The interpretation of aortography is based on visual estimation of intrusion, width and radiodensity of the regurgitant flow, and is affected by angiographic projection, catheter position, rate and volume of contrast injection, influence of the contrast medium on central hemodynamics, size of the aortic root and left ventricle, and presence of mitral regurgitation[20,22]. These Doppler indexes may be used to obviate particular limitations of the invasive measurement. Furthermore, it should improve the routine assessment and follow-up of patients with AR, which remains a difficult clinical problem despite the contribution of the echocardiographic assessment of left ventricular dimensions[23,24]. Color and pulsed Doppler therefore should now be considered the diagnostic modality of choice in most patients with AR because of its low cost, repeatability, and noninvasive approach.

There are a number of limitations in this study: the number of patients was small, angiographic grading is a semiquantitative evaluation of AR which has been considered less than gold standard, and Doppler examination was not performed simultaneously with angiography. Despite these limitations, color and pulsed Doppler correlated with and were predictive of angiographic grade.

In conclusion, the severity of AR in children as determined by angiographic grading can be estimated with reasonable accuracy by noninvasive technique based on color and pulsed wave Doppler. Use of these indexes may obviate the need for angiography to detect the severity of AR in children.

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