Assessment of the severity of aortic regurgitation with pulsed wave Doppler velocity profile in the descending aorta

Belma Kalaycı, Süleyman Kalaycı[1], Pınar Türker Bayır[2], Serkan Duyuler[1], Saadet Güven[1], Taner Şen[1], Omaç Tüfekçioğlu[1]

Clinic of Cardiology, Karaman State Hospital; Karaman-*Turkey*
[1]Clinic of Cardiology, Türkiye Yüksek İhtisas Hospital; Ankara-*Turkey*
[2]Clinic of Cardiology, Muş State Hospital; Muş-*Turkey*

Abstract

Objective: The quantitative parameters which are used to assess the severity of aortic regurgitation (AR) provide the most accurate information whereas these parameters are difficult and time-consuming. The aim of this study was to get a practical parameter to use in daily practice for assessing the severity of aortic regurgitation.
Methods: The study was an observational cohort study on diagnostic accuracy of severity of aortic regurgitation. Thirty-seven patients with aortic regurgitation determined by quantitative parameters (18 patients with severe aortic regurgitation and 19 patients with moderate aortic regurgitation) were included in this study. Each patient's diastolic flow pattern in the descending aorta was examined by pulsed wave Doppler. Systolic and diastolic flow time-velocity integral (TVI), TVI time, systolic and diastolic TVI ratio in the descending aorta were evaluated. In addition to these parameters, dP/dt, peak acceleration time and end-diastolic flow velocity in the diastolic flow were determined. We investigated whether there a significant difference between two groups or not. Receiver operating characteristic (ROC) analysis was used to determine the optimal cut-off values of echocardiographic parameters which were used to identify the severity of aortic regurgitation.
Results: The study population was composed of 16 female and 21 male patients. Their mean age was 46.5 years. The mean diastolic flow TVI of patients who had moderate and severe aortic regurgitation was found 10.1 cm and 18.6 cm, respectively (p<0.001). In the ROC curve analysis, the values of diastolic flow TVI above 13.5 cm was found to have 83% sensitivity and 90% specifity to predict the severity of aortic regurgitation (AUC: 0.91, 95% CI 0.80-1.0, p<0.001). Also we investigated the other parameters like systolic flow TVI, the ratio of systolic and diastolic flow TVI, mean diastolic flow time, mean systolic flow time, the ratio of systolic and diastolic flow time, end-diastolic velocity, peak acceleration time, dP/dt values in evaluation of diastolic flow in the descending aorta. These parameters were found statistically significant in assessing the severity of aortic regurgitation but their statistical power was weak.
Conclusion: TVI of diastolic flow which is measured with pulsed wave Doppler in descending aorta could be a practical parameter in assessing the severity of aortic regurgitation. *(Anadolu Kardiyol Derg 2014; 14: 427-33)*
Key words: aortic regurgitation, diastolic flow in the descending aorta, pulsed wave Doppler velocity

Introduction

Continuous wave Doppler, pulsed Doppler and color Doppler flow have been widely used to assess the severity of chronic aortic regurgitation (AR) (1-4). In recent guidelines, it is recommended to use quantitative, semi-quantitative and qualitative echocardiographic parameters together for assesing the severity of AR. The most accurate results can be achieved by quantitative methods (5). However, these methods are time-consuming and they have interobserver variability due to the absence of a hierarchical weighting of discordant parameters. Therefore, there are many differences among observers and determination of the most accurate parameter is very difficult.

New parameters are needed to determine the severity of aortic regurgitation and to reduce the differences among observers. Thus, with the help of echocardiography and magnetic resonance imaging, many studies have been performed to assess the severity of chronic aortic regurgitation (6, 7). Use of three-dimensional echocardiography for assessment of the severity of aortic regurgitation is an important for prosthetic valves (8-10). Transesophageal echocardiography (TEE) is suitable for patients who have poor acoustic window and inconclusive transthoracic echocardiography.

Previous studies have reported a good correlation between severity of aortic regurgitation and Doppler assessment of flow

Address for Correspondence: Dr. Belma Kalaycı, Karaman Devlet Hastanesi,
Kardiyoloji Kliniği, Karaman-*Türkiye*
Phone: +90 338 226 31 09 E-mail: drbelma@hotmail.com
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velocity at the end of diastole in the descending aorta just beneath the aortic isthmus (11-14). Also descending aorta velocity profile was more reliable than ascending aorta (15).

In this study, we aimed to reach a practical parameter which can be used in daily practice for assessing of the severity of aortic regurgitation in the descending aorta. We researched for found some parameters that easily available and without time consuming. We investigated correlation between the severity of aortic regurgitation and diastolic flow pattern in descending aorta.

Methods

Study design and population

Patients who were admitted to cardiology department of Türkiye Yüksek İhtisas Education and Research Hospital in Ankara between November 2010 and May 2011 and who had the diagnosis of moderate and severe aortic regurgitation were included in this study. This investigation was designed as a single center study. The study was an observational cohort study on diagnostic accuracy of severity of aortic regurgitation.

Exclusion criteria for the study were as follows: ejection fraction being less than 50%, severe mitral regurgitation, systolic pulmonary pressure more than 40 mm Hg, acute aortic regurgitation and acute infective endocarditis, history of previous valve or aortic surgery, coarctation of aorta, history of significant coronary artery disease, uncontrolled hypertension, diabetes mellitus and atrial fibrillation.

The history of significant coronary artery disease, uncontrolled hypertension and diabetes mellitus can influence aortic stiffness. Increased aortic stiffness can also change the results of the study. Therefore, these patients were excluded. The patients who had poor acustic window were not also included in this study.

Thirty-seven patients included in the study. Eighteen of 37 patients had severe AR and the rest 19 patients had moderate AR. Patients divided into two groups according to the severity of aortic regurgitation as moderate AR and severe AR groups.

All patients had sinus rhythm in electrocardiography. Patients with atrial fibrillation were excluded. Arterial blood pressure of the patients were measured after a 15-minute resting with the same sphygmomanometer.

Study protocol

The study protocol was approved by the Committee of the Research and Medical Ethics of Türkiye Yüksek İhtisas Education and Research Hospital in 2010. All patients were informed about the study and their consents were obtained.

Demografic and clinical features of the patients are presented in Table 1. All patients underwent standard transthorasic echocardiography examination. Parasternal long-axis, parasternal short axis, suprasternal view, subcostal view, apical four-and-five chamber view were used for determine of aortic regurgitation etiology and severity. We researched correlations between quantitative parameters and pulsed wave Doppler velocity profile in the descending aorta. Systolic flow time velocity integral (TVI), diastolic flow TVI, thr ratio of systolic flow TVI to diastolic flow TVI, systolic flow time, diastolic flow time, the ratio of systolic flow time to diastolic flow time, end-diastolic velocity, peak diastolic flow acceleration time and dP/dt were measure in the descending aorta.

Echocardiographic examination

All patients underwent transthoracic echocardiographic examination by Vivid 7 Dimension (General Electric, Fairfield, CT, USA) echocardiography device with a 2.5-3.5 MHz transducer. Ejection fraction, left ventricular end-systolic, and end-diastolic diameters and diameters of ascending aorta were measured.

After routine echocardiographic examination, aortic regurgitation (AR) /left ventricular outflow tract (LVOT) jet ratio was measured by using parasternal long-axis view. Pressure half time (PHT) and vena contracta of aortic regurgitation values were recorded from the apical five-chamber views with continuous wave Doppler and color Doppler flow, respectively. Aortic valve and leaflet morphology were evaluated from the parasternal short-axis view at the aortic level and the information about etiology of aortic regurgitation was obtained. Pulmonary valve annulus diameter and pulmonary TVI were measured to calculate the blood flow, by placing the pulsed wave sample volume on pulmonary valve level. Regurgitant volume (RV), regurgitant fraction (RF) and effective regurgitant orifice area (EROA) were calculated. All values were used to decide the severity of aortic regurgitation and patients were divided into moderate and severe AR groups.

Transducer was positioned at the suprasternal notch and ultrasound beams were provided to directly fall on the thoracic aorta. The 10 mm in size sample volume was placed distal to left subclavian artery. Doppler beams were tried to be in parallel with the aortic blood flow axis. Time and flow velocity, peak acceleration time, dP/dt value, TVI of diastolic flow were measured in the descending aorta. PW Doppler recordings and dP/dt measurements were shown in Figure 1. In adition, systolic flow time and TVI of systolic flow of the aorta were measured. The correlation of the severity of AR were investigated.

In the study echocardiographic examination was performed by a single investigator. After the procedure all of findings have been verified by a supervisor. Inter-observer agreement rates were 0.953 (95% CI: 0.943, 0.964).

Statistical analysis

Statistical analysis was performed by using SPSS 17.0 (Chicago, Illinois). Parametric data were expressed as mean±standard deviation and qualitative data as numbers and percentages. Differences between groups were assessed by the Student's t-test for normally distributed quantitative variables. Chi-square test was used to compare non-parametric categorical variables between groups. ROC (receiver operating characteristic) analysis was used to determine the optimal cut-off values of echocardiographic parameters which were used to identify the severity of aortic regurgitation with maximum sensitivity and specificity. Statistical significance was defined as p<0.005.

Results

Thirty-seven patients, 16 females (43.2%) and 21 males (56.8%) were included in this study. 18 patients had severe AR whereas 19 patients had moderate AR. Additionally, there were 11 female (57.9%) and 8 male (42.1%) patients in moderate aortic regurgitation group and 13 males (72.2%) and 5 female (27.8%) patients in severe aortic regurgitation group. Although men were more likely to have severe aortic regurgitation, this did not differ in our study (p=0.065). The mean age of the patients who have moderate aortic regurgitation and severe aortic regurgitation was 48.3 and 41.8 years; respectively (p=0.24). There was no statistically remarkable difference between the groups related to age, LVEF and ascending aortic diameter. Mean systolic arterial pressure was 138.25 mm Hg and diastolic arterial pressure was 67.05 mm Hg.

Only 28% (n:4) patients received benzathine penicillin for acute rheumatic fever prophylaxis among study patients who had rheumatic heart disease. Three of them were in severe group and one of them was in moderate group. This means that rate of acute rheumatic fever prophylaxis was very low rate in study population. But this result can not be generalized due to the low number of sample.

Baseline characteristics of study patients were shown in Table 1. Age, pulse pressure, drugs used and valve morphology was evaluated between the two groups. Echocardiographic measurements of the apical and parasternal windows and statistical analysis between the groups was shown in Table 2. As expected, AR to LVOT jet ratio (AR/LVOT jet), AR PHT, regurgitant volume, regurgitant fraction, vena contracta and EROA was found significantly high for patients with severe AR. The parameters used in the evaluation of systolic and diastolic flow in descending aorta was shown in Table 3. There was no statistically significant difference in respect to etiology of AR (p=0.1).

In general, 54.1% of patients had left ventricular hypertrophy as well and this ratio was 72.2% for severe AR group and 36.8% for moderate AR group (p=0.03). There was no patient who had

Table 1. Baseline characteristics of patients

Variables	Severity of AR	Values*	N	%
Age	Moderate	48.3±16.6	19	-
	Severe	41.9±16.1	18	-
Pulse pressure	Moderate	69.4±14.7	19	-
	Severe	76.3±16.9	18	-
Sex, women	Moderate	-	11	68.8
	Severe	-	5	31.3
Sex, men	Moderate	-	8	38.1
	Severe	-	13	61.9
Degenerative valve	Moderate	-	11	55.0
	Severe	-	9	45.0
Fibrotic valve	Moderate	-	8	61.5
	Severe	-	5	38.5
Bicuspid valve	Moderate	-	0	0
	Severe	-	3	100
Beta bloker	Moderate	-	7	53.8
	Severe	-	6	46.2
ACEİ/ARB	Moderate	-	5	35.7
	Severe	-	9	64.3
CCB	Moderate	-	5	38.4
	Severe	-	8	61.6
Diuretics	Moderate	-	3	42.8
	Severe	-	4	57.2

Data are presented as mean±SD and number
*Student t-test, chi-square test
ACEI - angiotensin-converting enzyme inhibitors; ARB - angiotensin receptor blockers; CCB - calcium channel blockers; N - number of patients

Table 2. Echocardiographic measurements of the apical and parasternal windows and statistical analysis between two groups

Variables	Severity of AR	Mean values± standart deviation*	*P**
AR /LVOT jet	Moderate	0.42±0.7	0.000
	Severe	0.65±0.13	
Vena contracta, cm	Moderate	0.41±0.9	0.000
	Severe	0.62±0.9	
AR PHT, ms	Moderate	379.7±119.9	0.002
	Severe	272.4±71.7	
Regurgitant fraction, %	Moderate	54.3±17.9	0.003
	Severe	70.9±12.5	
Regurgitant volume, mL	Moderate	39.9±18.2	0.000
	Severe	84.5±26.7	
EROA, cm^2	Moderate	0.25±0.3	0.003
	Severe	0.5±0.2	
Diameter of the ascending aorta (cm)	Moderate	3.9±0.6	0.228
	Severe	4.0±0.7	
LVEDD, cm	Moderate	5.4±0.5	0.001
	Severe	6.0±0.5	
LVESD, cm	Moderate	3.6±0.5	0.006
	Severe	4.2±0.6	
LVEF, %	Moderate	60.5±6.1	0.332
	Severe	58.3±7.1	

AR PHT - aortic regurgitation pressure half time; EROA - effective regurgitant orifice area; LVEDD - left ventricule end-diastoic; LVESD - left ventricular end-systolic diameter; LVEF - left ventricle ejection fraction; LVOT - left ventricle outflow tract
*Levene's test for equality of variances, t-test for equality of means, one sample Kolmogorov-Smirnov test

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Table 3. The parameters used in the evaluation of systolic and diastolic flow in descending aorta in moderate and severe AR groups (TVI- time velocity integral)

Variables	Severity of AR	Mean values± standart deviation	*P**
Systolic flow TVI, cm	Moderate	17.8±5.1	0.130
	Severe	21.4±8.7	
Diastolic flow TVI, cm	Moderate	10.1±3.3	0.000
	Severe	18.6±7.9	
Systolic flow TVI /	Moderate	1.9±0.9	0.002
Diastolic flow TVI	Severe	1.2±0.5	
Systolic flow time, ms	Moderate	255±36.2	0.853
	Severe	257.3±38.2	
Diastolic flow time, ms	Moderate	369±133.9	0.000
	Severe	530.9±109.7	
Systolic flow time/	Moderate	0.7±0.4	0.007
Diastolic flow time	Severe	0.5±0.1	
End-diastolic velocity, m/s	Moderate	0.15±0.06	0.000
	Severe	0.3±0.08	
Peak diastolic flow acceleration time, ms	Moderate	9.5±3.2	0.031
	Severe	7.3±2.8	
dP/dt, mm Hg/s	Moderate	28.9±12.3	0.002
	Severe	45.4±16.9	

*t-test

moderate or severe gradient in aortic valve level. Only two patients with left ventricular hypertrophy had mild gradient (mean gradient <20 mm Hg). Both patients were in severe AR group.

All patients had a reverse diastolic flow in the descending aorta. The patients with the severe AR had a reverse flow during diastole (pandiastolic flow) (Fig. 1, 2), but 10.6% of the patients with moderate AR had a reverse flow during diastole. Pandiastolic flow can be shown in the suprasternal window by color M-mode in Figure 3.

Mean diastolic flow TVI was found 10.1 cm and 18.6 cm for moderate AR and severe AR groups, respectively (p<0.001). In the ROC curve analysis, AUC (area under the curve) value of diastolic flow TVI was 0.91 for the patients with severe AR and the test was found to have 83% sensitivity and 90% specifity at the values above 13.5 cm (AUC: 0.91, 95% CI: 0.80-1.0, p<0.001). Furthermore, while the ratio of systolic and diastolic flow TVI was found 1.9 for moderate AR group, it was 1.1 for severe AR group, (p=0.002). The ROC curve analysis diagram of the diastolic reverse flow time and diastolic flow TVI for the evaluation of severe AR in Figure 4.

End-diastolic velocity of the reverse flow in the descending aorta was found 0.15 m/s for moderate AR group and 0.29 m/s for severe AR group (p<0.001). Measurements was done at the peak of R wave on the spontaneous recorded electrocardiogram with 10 mm sample volume width. In the ROC curve analysis, AUC

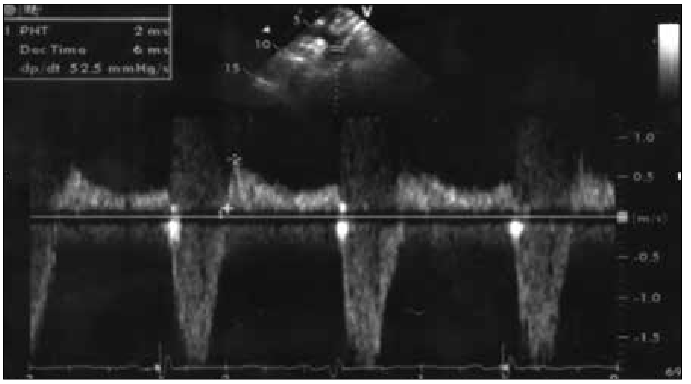

Figure 1. Measurement of dP/dt by PW Doppler by placing the sample size distal to the subclavian artery

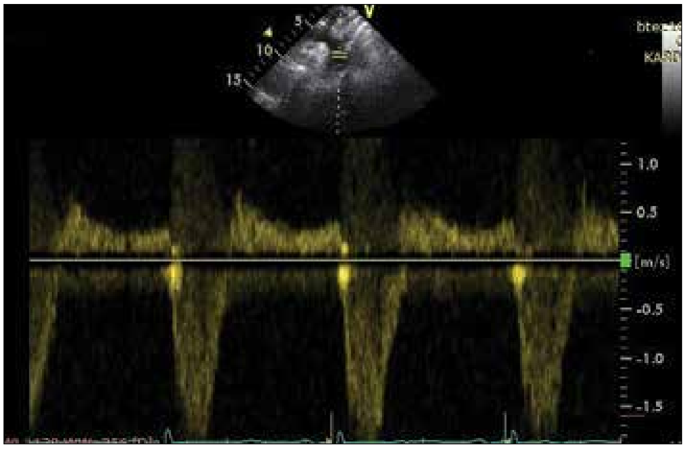

Figure 2. The patients with the severe AR had a reverse flow during diastole (pandiastolic flow) was shown by PW Doppler by placing the sample size distal to the subclavian artery
AR - aortic regurgitation

(area under the curve) value of end-diastolic velocity of the reverse flow was 0.96 in severe AR group.

The cut-off values of parameters of diastolic reverse flow in the descending aorta and their statistical power were evaluated by ROC curve analysis. It was shown in Table 4.

Discussion

In the present study, we investigated the relationship between severity of aortic regurgitation and pulsed wave Doppler velocity profile in the descending aorta. Diastolic flow TVI, diastolic flow time, systolic flow TVI/ diastolic flow TVI, systolic flow time/diastolic flow time, diastolic flow dP/dt and peak diastolic flow accelaration time were significant correlation with quantitative echocardiographic parameters. But diastolic flow TVI was more strong correlation.

In recent guidelines, it is recommended to use quantitative, semi-quantitative and qualitative echocardiographic parameters together for assesing the severity of AR. Quantitative methods are most reliable but they are difficult and time-consuming. Evaluation of diastolic flow in the descending aorta may be used for assessment severity of aortic regurgitation. These evaluations must be

Table 4. Pulsed wave Doppler evaluation of diastolic reverse flow in the descending aorta. ROC curve analysis of the performance of pulsed wave Doppler velocity profile parameters for demonstrate severity of aortic regurgitation (AUC-area under the curve)

Variables	AUC	Cut-off value	Specificity %	Sensitivity %	95% CI	*P*
Peak diastolic flow acceleration time, ms	0.69	8.5	58	67	0.52-0.86	0.04
Diastolic flow dP/dt, mm Hg/s	0.81	>29.5	69	83	0.66-0.95	0.001
Diastolic flow TVI, cm	0.91	>13.5	90	83	0.80-1.0	0.000
Systolic flow TVI/Diastolic flow TVI	0.79	<1.57	63	78	0.63-0.93	0.003
Diastolic flow time, ms	0.84	427	74	89	0.71-0.97	0.001
Systolic flow time/Diastolic flow time	0.81	<0.530	79	83	0.65-0.96	0.001

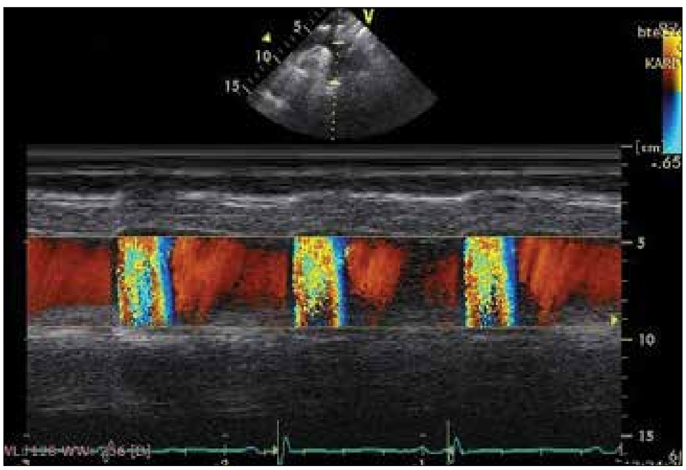

Figure 3. Pandiastolic flow can be shown in the suprasternal window by color M-mode

matched with the values in the quantitative parameters. But gold standard for assesment of the severity of the aortic regurgitation is magnetic resonance imaging and catheterization. Therefore, echocardiographic parameters should be compared with magnetic resonance imaging or catheterization for best actual result.

We decided the severity of aortic regurgitation with quantitative parameters and supportive parameters. Aortic regurgitation pressure half time (AR PHT) is one of the supportive parameters. AR PHT reflects aortic and LV diastolic pressure equalization rate. AR PHT depends on diastolic blood pressure and diastolic compliance of left ventricle. Therefore, if LV diastolic pressure increased or vasodilatator treatment was given to the patient, PHT would shorten. In the chronic period, PHT would extend via LV adaptation and this can lead to poor AR diagnosis. So, the measured PHT value does not always reflect the actual diagnosis. Likewise some clinical situations may lead to incorrect assessment of severity of aortic regurgitation. For example, severe mitral regurgitation can interfere PHT measurements. In this situtaion, the calculation of the pulmonary blood flow gives more accurate results. Patients with severe mitral regurgitation were excluded in this study. We assumed that mild and moderate mitral regurgitation may affect the results of a study changing mitral inflow. Pulmonary flow calculation could be an alternative way in calculation of mitral inflow.

In daily practice, dP/dt is an isovolumic phase index used to determine the severity of mitral regurgitation. In a study it was

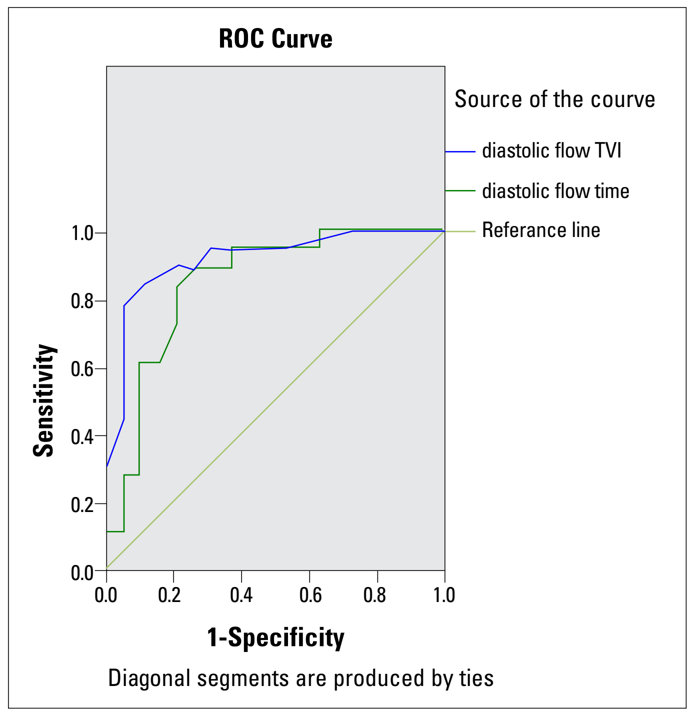

Figure 4. The ROC curve analysis of the diastolic reverse flow time and TVI of diastolic flow for the evaluation of severe AR
AR - aortic regurgitation; ROC - receiver operating characteristic; TVI - time velocity integrad

shown that Doppler-derived dP/dt was a good predictor of postoperative left ventricular systolic function in patients with chronic aortic regurgitation (16). Furthermore, in an another study, authors concluded that continuous-wave Doppler velocity profile of aortic regurgitation could be used for assessing noninvasively the contractile state of the left ventricle (17). Several studies have demonstrated a good correlation between catheter derived and Doppler derived dP/dt (11, 18). In our study dP/dt was associated with severe AR even though statistical significance was not strong. There is a need for further investigation for clinical applications. The diagram of ROC curve analysis of dP/dt value for pulsed Doppler evaluation in the descending aorta on the diastolic reverse flow was shown in Figure 5.

Triouilloy et al. (15) showed that Doppler assessment of flow velocity at the end of diastole in the descending aorta just beneath the aortic isthmus was a good indicator of the severity of aortic regurgitation. They also concluded that end-diastolic flow velocity of >18 cm/s had sensitivity of 88.5% and a specific-

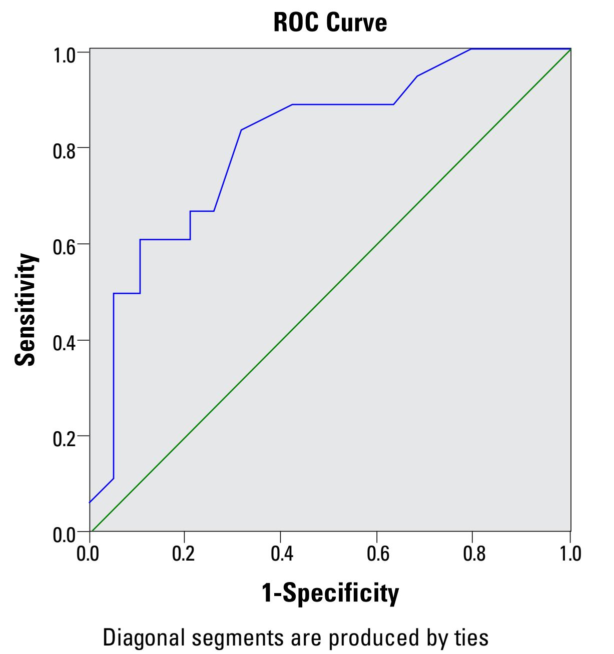

Figure 5. ROC curve analysis of dP/dt value for pulsed wave Doppler evaluation in of the diastolic reverse flow in the descending aorta

ity of 96% in prediction of regurgitant fraction ≥40%. In our study, mean end-diastolic flow velocity was 15 cm/s for moderate AR group while it was 29 cm/s for severe AR group (p<0.001). Also statistical significant was very strong. In the ROC curve analysis, AUC value of end -diastolic velocity of the reverse flow was 0.96 in severe AR group. We investigated about correlation between end diastolic velocity and diastolic flow TVI with correlation analysis. According to Pearson correlation analysis their correlation was very significant (r=0.69, p<0.001).

Previous studies showed that forward and reverse flow profiles in the ascending aorta can be irregular and unreliable (12, 13). However, there are other studies showing that descending aorta velocity profile was more reliable (14, 15). Furthermore, movement during cardiac cycle is much less in the aortic isthmus than the ascending aorta, allowing better positioning of the sample volume (15). The measurements in early diastole were affected by the aortic wall compliance, so they were not used in identification (13).

Prediction of severity of valvular regurgitation by chest radiography may lead to false interpretations. Cardiac enlargement on chest radiography had only 50% of patients in the group of severe aortic regurgitation patients but 100% patients with severe aortic regurgitation on echocardiography (19). Furthermore radiography poor relation was detected between the severity of aortic regurgitation and cardiac enlargement on chest radiography.

There is no single quantitative parameter to determine the severity of aortic regurgitation. For this reason, multiple parameters must be used and be verified with each other to determine the severity of AR. Therefore, the quantitative measurements are very valuable. In the present time, alternative methods are needed to assess the severity of aortic regurgitation as an alternative to transtoracic echocardiography. In a study in the same purpose, it was found that the phase-contrast measurements, which were done in the proximal ascending aorta with cardiac magnetic resonance had relation with transthoracic echocardiographic measurements, but they were different from known quantitative parameters (7). Phase contrast cardiac magnetic resonance measurements depend on the respiratory cycle and the measurements can be effected by breath-hold, breath-kept protocols (20). Measurements for breath-hold protocols are higher. Out of this difficulty magnetic resonance imaging is more reliable technique for assesing of severity of the aortic regurgitation.

Study limitations

The main limitation of this study is small sample size. The larger sample size could increase the reliability and generalizability of the study. However this trial may lead to further studies on this subject.

Drugs used by the study patients was shown in Table 1. Some patients were using more than one drug. But we can say angiotensin-converting enzyme inhibitors and angiotensin receptor blockers more used in severe AR group and beta-blocker more used in moderate AR group. Nevertheless effect of these drugs on the results were not examined. These assessment may perform with larger sample size. So we reach most reliable information about interactions between drugs and echocardiographic parameters.

If the results would have been been correlated with magnetic resonance imaging or catheterization, the study was more reliable and actual. Further studies with larger cohorts of patients are warrented to reveal the relationship between severity of aortic regurgitation and diastolic velocity profile in the descending aorta.

Conclusion

This study was designed to reach a practical parameter, which can be used in daily practice for assessing the severity of aortic regurgitation. This study shows that the measuremets of diastolic reverse flow in the descending aorta may evaluate the severity of aortic regurgitation more easier than quantitative parameters. TVI of diastolic flow exceeding 13.5 cm in the descending aorta with pulsed Doppler identified patients with severe aortic regurgitation with high sensitivity and spesificity.

Conflict of interest: None declared.

Peer-review: Externally peer-reviewed.

Authorship contributions: Concept - B.K., O.T.; Design - O.T.; Supervision - O.T.; Resource - B.K., S.K.; Materials - T.Ş., S.K.; Data collection&/or processing - B.K., S.K.; Analysis &/or interpretation - B.K., S.K.; Literature search - B.K., T.Ş.; Writing - B.K., S.K.; Critical review - B.K., S.K., S.G.; Other - P.T.B., S.D.

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