Evaluation of left ventricular function with strain/strain rate imaging in patients with rheumatic mitral stenosis

Romatizmal mitral darlığı olan hastalarda sol ventrikül fonksiyonlarının strain/strain rate görüntüleme ile değerlendirilmesi

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ABSTRACT

Objective: The most important sequel of acute rheumatic fever is mitral stenosis in long-term. The aim of the study is to determine left ventricular (LV) functions by tissue Doppler imaging (TDI) and strain/strain rate echocardiography (SE/SRE) in mitral stenosis patients who had no clinical signs of heart failure.
Methods: Our study was designed as cross-sectional study. The study population consisted of 32 patients with isolated mitral stenosis and mitral valve area < 2.0 cm^2 (Group 1) and 25 healthy control subjects (Group 2). In addition to standard echocardiographic methods, TDI and SE/SRE were performed to assess LV functions in all participants. Student's t-test was used to compare continuous variables. Fisher- exact test was used to compare categorical variables.
Results: Systolic myocardial velocity (Sm) were significantly lower in Group 1 than in Group 2 (6.0±1.4 cm/sec vs 7.9±1.8 cm/sec, p<0.001) also, early diastolic myocardial velocity (Em) were significantly lower in Group 1 than in Group 2 (4.4±1.5 cm/sec vs 10.8±2.1 cm/sec, p<0.001). But there was no significant difference in late diastolic myocardial velocity (Am) between two groups. Peak systolic strain and strain rate of septal wall in Group 1 were significantly lower than Group 2 (p<0.001 for both). Besides, peak systolic strain and strain rate of lateral wall in Group 1 were significantly lower than in Group 2 (p<0.001 for both).
Conclusion: Although, global ejection fraction were normal and there were no symptoms of heart failure clinically in the patients with mitral stenosis, LV dysfunction demonstrated that using by echocardiography. TDI and strain/strain rate imaging to be new echocardiographic methods may be used reliably for detection LV function in early stage of mitral stenosis. *(Anadolu Kardiyol Derg 2010; 10: 328-33)*
Key words: Mitral stenosis, echocardiography, strain/strain rate imaging, left ventricular function

ÖZET

Amaç: Akut romatizmal ateşin uzun dönem en önemli sekeli mitral darlığıdır. Bu çalışmanın amacı, klinik olarak kalp yetersizliği bulguları olmayan mitral darlığı olan hastalarda, sol ventrikül (LV) fonksiyonlarının doku Doppler görüntüleme (TDI) ve strain/strain rate ekokardiyografi (SE/SRE) teknikleri ile değerlendirilmesidir.
Yöntemler: Çalışmamız enine-kesitli olarak dizayn edildi. Çalışmamıza 32 izole mitral darlığı olan, mitral kapak alanı <2.0 cm^2 (Grup 1) ve 25 sağlıklı gönüllü birey (Grup 2) alındı. Tüm bireylerin konvansiyonel ekokardiyografilerine ek olarak, TDI ve SE/SRE teknikleri uygulanarak LV fonksiyonları değerlendirildi. Sürekli değişkenlerin karşılaştırılmasında Student t-testi, kategorik değişkenlerin karşılaştırılmasında Fisher-exact testi kullanıldı.
Bulgular: Sistolik miyokardiyal hız (Sm) Grup 1'de, Grup 2'den önemli oranda daha düşük bulundu (6.0±1.4 cm/sn karşın 7.9±1.8 cm/sn, p<0.001), aynı zamanda erken diyastolik miyokardiyal hız (Em) Grup 1'de, Grup 2'den önemli oranda daha düşük bulundu (4.4±1.5 cm/sn karşın 10.8±2.1 cm/sn, p<0.001). Fakat iki grup arasında geç diyastolik miyokardiyal hız (Am)'lar açısından anlamlı bir farklılık görülmedi. Grup 1'de septal duvar pik sistolik strain/strain rate değerleri, Grup 2'den anlamlı olarak düşük bulundu (p<0.001, p<0.001). Beraberinde Grup 1 lateral duvar pik sistolik strain/strain rate değerleri de Grup 2' den önemli oranda düşük bulundu (p<0.001, p<0.001).
Sonuç: Bu ekokardiyografi metodları ile global ejeksiyon fraksiyonları normal ve klinik olarak kalp yetersizliği olmayan mitral darlığı olan hastalarda LV disfonksiyonu olduğu görüldü. TDI ve strain/strain rate görüntüleme teknikleri, yeni ekokardiyografik yöntemler olup mitral darlıklı hastalarda erken evrede LV fonksiyonlarını değerlendirmede kullanılabilirler. *(Anadolu Kardiyol Derg 2010; 10: 328-33)*
Anahtar kelimeler: Mitral darlığı, ekokardiyografi, strain/strain rate görüntüleme, sol ventrikül fonksiyonları

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Introduction

Measuring myocardial performance has a critical importance in diagnosis and treatment of patients with cardiac diseases. The researches for the most appropriate method to measure contractile characteristics of myocardium are still carrying on.

Rheumatic mitral valve stenosis affects the left ventricle (LV) functions at various levels due to inflammatory and hemodynamic factors. Generally, LV systolic function in isolated mitral valve stenosis is well preserved (1). In a few patients with mitral valve stenosis, ultrastructural, pathological alterations might occur in the muscle cells of the LV. In proportion with these alterations, contractile functions of the LV also decrease (2). Subclinical systolic dysfunction has been shown via tissue Doppler imaging (TDI) in patients with mitral valve stenosis (3-5). In TDI velocity analysis, used for the evaluation of regional myocardial functions, some problems, such as continuing elongation of myocardium-like structures and transmission of active and passive deformation in adjacent segments have been encountered. Additionally, the heart becomes relatively distant from the transducer due to respiration, which affects velocities results (6). In order to overcome these problems, strain echocardiography (SE) and strain rate echocardiography (SRE) techniques have been developed. SE and SRE techniques are found to be superior to tissue Doppler velocities since they are independent from the push-pull effect of adjacent segments. While SE is affected by preload and heart rate, SRE shows parallelism to inotropic conditions and contractility, independently from the loading conditions (7, 8). Recently, it was reported in several studies that, subclinical LV dysfunction was demonstrated via that imaging methods in patients having pure mitral stenosis and normal LV function with traditional echocardiography (9-11). In these studies, commonly, particular segments of LV were evaluated. However, in this study, we evaluated all of the LV segments globally.

The aim of the present study was to investigate whether the SE/SRE technique is advantageous in evaluation of LV systolic function in patients with pure mitral valve stenosis.

Methods

In the present cross-sectional study, 32 patients (25 females, 7 males; mean age 39±8 years) with isolated mitral valve stenosis that were asymptomatic or had minimal symptoms (class I or class II according to NYHA) and 25 control cases (19 females, 6 males; mean age 38±6 years) were included. According to the mitral valve area (MVA), 14 patients had mild stenosis (MVA: 1.5-2.0 cm^2), 15 had moderate (MVA: 1-1.5 cm^2), and 3 had severe stenosis (MVA: <1.0 cm^2). None of the patients presented clinical symptoms of heart failure. Those with atrial fibrillation, diabetes mellitus, hypertension, coronary artery disease, moderate-severe aortic and mitral regurgitation, aortic stenosis, hyperthyroidism, chronic obstructive pulmonary disease, atrioventricular conduction abnormality, segmental wall motion abnormalities, severely calcified mitral valve structure, and decreased global LV systolic function were not included in this study.

All of the participants were informed about the procedure and their written consents obtained. The University's Ethics Committee granted approval for the present study.

Echocardiography

The echocardiographic examination was performed in the left lateral position with a Vingmed ultrasound system (Vingmed System 7, General Electric, Horten, Norway) and a 2.5 MHz transducer. The patients were monitored through a single-lead electrocardiogram. Diameters of the LV end-systolic (LVSD), LV end-diastolic (LVDD) and left atrium (LA), thickness of interventricular septum (IVS) and LV posterior wall (PW) were measured in M-mode from the parasternal long-axis (12). Right atrial (RA) and right ventricular (RV) diameters were measured from the apical four chambers. Peak and mean transmitral pressures were measured via Doppler. MVA was measured planimetrically in 2-dimensional (2D) images from the parasternal short axis and using the pressure half-time method by applying continuous wave (CW) Doppler during apical four-chamber view of the mitral valve. The area was calculated by the mean value of two measurements. The valvular insufficiency was evaluated by color flow Doppler imaging. LV ejection fraction (LVEF) was calculated via both Teichholz and modified Simpson's methods. Systolic myocardial velocity (Sm), early (Em) and late diastolic velocities (Am) were measured in the basal lateral segment and basal interventricular septum from the apical four chambers views using TDI. The velocities were calculated by the mean value of two measurements. Pulmonary artery systolic pressure (PASP) was measured by adding 10 mmHg, considering the diameter of vena cava inferior and the level of its collapse resultant from respiration, to the value measured by evaluating Bernoulli equation, which is simplified from tricuspid insufficiency velocities.

SE/SRE Imaging

Echocardiographic measurements were obtained by two different cardiologists separately and then mean value of the both measures was calculated. Firstly, the wall on which the measurements from 2D imaging would be performed was positioned parallel to the transducer and the tissue velocity imaging (TVI) function was selected. Color Doppler myocardial imaging of LV lateral, septal, anterior and inferior walls were obtained in apical two and four chambers views with a frame rate >120/s. The images were acquired including one wall by obtaining the probable narrowest angle and the maximum frame rate values. These images, consisting of a minimum of three sequential sinus beats at the end of the expirium, were recorded on digital media. These color Doppler myocardial images were analyzed offline via Workstation, GE. Both longitudinal peak systolic strain rate (PSSR) and peak systolic strain (PSS) were measured from the basal, middle and apical segments of all walls (Fig. 1, 2). Measurements were performed just below the endocardium, by leaving a 10 mm distance between the two points. For each participant, either in patient or control groups, 12 segments were analyzed. Segments presenting either a weak image or an angle gradient greater than 25° were not evaluated.

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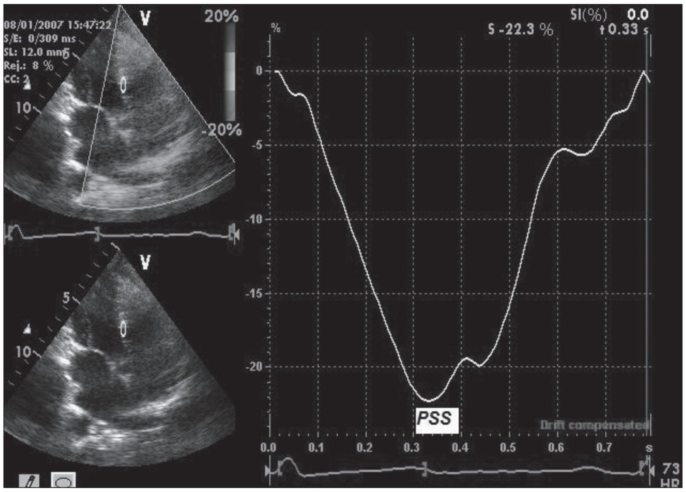

Figure 1. Peak systolic strain imaging of the mid septum in a mitral stenosis patient

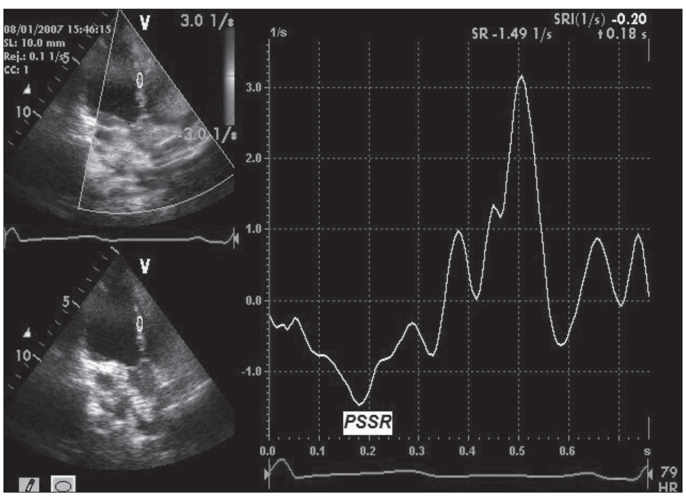

Figure 2. Peak systolic strain rate imaging of the mid septum in a mitral stenosis patient

Statistical analysis

The Statistical Package for the Social Sciences (SPSS Inc, Chicago, Illinois, USA) version 10.0 was used for statistical analysis. Continuous variables were expressed as mean (±) standard deviation (SD). Student's t-test was used to compare the normally distributed continuous variable between the patients with mitral valve stenosis and the healthy control group. Fisher-exact test and Chi-square test were used to compare categorical variables.

Results

The echocardiographic and demographic parameters of the participants are shown in Table 1. The groups were similar in terms of age, gender and body mass index (BMI). There was no difference between the groups regarding echocardiographic parameters, namely the LVSD, LVDD, IVS, PW and LVEF. In the patient group, the mean MVA was 1.42±0.3 cm^2, whereas the peak and the mean mitral pressure gradients were 16±4.3 mmHg and 8.8±2.8 mmHg, respectively. The diameters of LA, RA and RV were significantly greater in the patient group compared to the control group. The mean PASP was found to be 40±17.5 mmHg in the patient group.

Table 1. General characteristics of the patients with mitral stenosis and healthy controls

Variables	Group 1 (n=32)	Group 2 (n=25)	p**
Age, years	39±8	38±6	0.42
Gender, F/M, n*	25/7	19/6	0.87
BMI, kg/m^2	27.1±3.4	26.5±3	0.5
MVA, cm^2	1.42±0.3	-	
LVDD, mm	45.6±5.1	44.2±4.1	0.26
LVSD, mm	30.4±3.5	30±3.6	0.13
IVS, mm	8.3±1.1	8.9±1.4	0.09
PW,mm	8.8±1.2	9.1±1.4	0.42
LVEF Teichholz, %	63.4±3.9	65.4±4.4	0.07
LVEF Simpson, %	62.3±4.6	64.5±4.3	0.08
LA,mm	46±6.8	32.2±3.5	<0.001
RA,mm	37.8±5.1	35.3±2.7	<0.05
RV, mm	37.9±5.2	34.6±2.9	<0.05
PASP, mmHg	40±17.5	-	

Data are presented as mean (±) standard deviation and *proportions
** Student's t-test and Fisher-exact tests.
BMI-body mass index, IVS- interventricular septum, LA-left atrium, LVDD-left ventricle end-diastolic diameter, LVEF- left ventricle ejection fraction, LVSD- left ventricle end-systolic diameter, MVA- mitral valve area, PASP- pulmonary artery systolic pressure, PW-posterior wall, RA- right atrium, RV- right ventricle

Sm was significantly lower in Group 1 than in Group 2 (6.0±1.4 cm/sec vs 7.9±1.8 cm/sec, p<0.001). Also, Em was significantly lower in Group 1 than in Group 2 (4.4±1.5 cm/sec vs 10.8±2.1 cm/sec, p<0.001). However, there was no significant difference in Am between two groups.

Of the total 684 segments evaluated in patient and control groups, 56 segments (8%) for PSSR and 29 segments (4%) for PSS were excluded from the study due to increased angle gradient (>25°) and poor signal-image. The PSS and PSSR values of the basal, mid and apical segments of the LV's lateral, septal, anterior and inferior walls were found significantly lower in the patient group than the control group (p<0.001) (Table 2).

Discussion

In this study, a subclinical LV dysfunction was documented in patients having normal LV function and pure mitral stenosis that showed via traditional echocardiography methods.

Myocardial performance measurement has critical importance on diagnosis and treatment of patients with cardiac disease. Though how long time passed, studies for discovering the most useable method that can evaluate myocardial contractile capacity are still carrying on (13). Relatively a small number of studies for the patients with mitral stenosis according to evaluation of clinical and echocardiographic monitoring and progres-

Table 2. Values of peak systolic strain and peak systolic strain rate in studied groups

Variables	Peak systolic strain			Peak systolic strain rate		
	Group 1 (n=32)	Group 2 (n=25)	p*	Group 1 (n=32)	Group 2 (n=25)	p*
Basal Lateral	-13.2±1.7	-15.8±1.8	<0.001	-1.22±0.14	-1.49±0.20	<0.001
Mid Lateral	-13.4±1.5	-17.4±1.9	<0.001	-1.21±0.17	-1.48±0.20	<0.001
Apical Lateral	-13.5±1.9	-16.5±1.9	<0.001	-1.27±0.2	-1.52±0.20	<0.001
Basal anterior	-14.1±1.7	-17.4±2.0	<0.001	-1.31±0.14	-1.53±0.15	<0.001
Mid Anterior	-14.2±2.4	-17.7±1.9	<0.001	-1.32±0.12	-1.57±0.14	<0.001
Apical anterior	-14.5±1.9	-17.3±2.1	<0.001	-1.36±0.16	-1.57±0.19	<0.001
Basal septum	-14.6±1.9	-19.6±1.7	<0.001	-1.29±0.16	-1.69±0.20	<0.001
Mid septum	-14.8±2.1	-20.7±1.8	<0.001	-1.30±0.18	-1.66±0.13	<0.001
Apical septum	-16.1±1.7	-20.3±2.1	<0.001	-1.35±0.16	-1.66±0.17	<0.001
Basal inferior	-13.9±1.7	-16.9±1.2	<0.001	-1.28±0.15	-1.46±0.15	<0.001
Mid inferior	-14.4±2.4	-17.5±1.4	<0.001	-1.28±0.15	-1.53±0.18	<0.001
Apical inferior	-15.1±1.3	-17.9±2.1	<0.001	-1.37±0.11	-1.55±0.21	<0.001

Data are presented as mean (±) standard deviation
*Student's t-test

sion of the disease are present in the literature. In a prospective clinical study that related to mitral stenosis patients with mean age of 28, it was reported that one half of the patients were asymptomatic at the time of diagnosis. Ten and twenty-year mortality rates were reported as 38% and 78%, respectively. Most of the death cases were resulted from heart failure or arterial emboli (14). In another study that related to mitral stenosis patients with mean age of 42, it was reported that at the time of diagnosis, 86% of the patients were asymptomatic and 10-year mortality rate was reported as higher (70%) (15). In the present study, mean age was 39.1±8 years. It was closer to the reported in the second study. None of the patients had any signs of congestive heart failure. If high mortality rates were taken in account, the importance of earlier diagnosis was apparent whether patients were asymptomatic at the time of diagnosis.

Left ventricular functions can be evaluated by M-mode, 2-dimensional and Doppler echocardiography. Measurements by these methods differ from physician to physician. Therefore, global ejection fraction could be determined in normal limits and deteriorations at the subclinical level could not be revealed, until the end stage of mitral stenosis. In this study, we aimed to evaluate systolic functions via SE/SRE methods among asymptomatic mitral stenosis patients who had normal conventional echocardiography findings.

Ejection performance of the LV is decreased in certain patients with mitral stenosis. This physiopathology is multifactorial; chronically decreased preload and increased afterload, regional hypokinesia caused by expansion of the scarred mitral valve over the posterobasal myocardium, and decrease in LV compliance due to IVS movement to the left side resultant from the rapid filling of the RV are the probable factors (16). In our study, the global LV functions of the patients, measured via EF, were within normal ranges. No segmental wall motion abnormalities were detected. The PASP was moderately increased and there was no difference between two groups regarding right heart dilatation. On the contrary, a considerable decrease was verified in LV systolic function on both SE and SRE.

Sengupta et al. (17) reported a significant improvement in tissue Doppler velocities after percutaneous mitral valvuloplasty in most of the patients with mitral stenosis that developed LV dysfunction. This improvement was found to be correlated with MVA and hemodynamic parameters. No improvement was observed in LVEF. The LV myocardium is affected at different levels due to the rheumatic inflammatory process. Through electron microscopy, Lee et al. (2) showed that there were ultrastructural pathological alterations within the myocardial cells of patients with mitral stenosis. These alterations were also seen within myofibrils and other cellular components. This finding was consistent in all the specimens examined regardless of the level of left ventricular contractile function. However, more extensive loss of myofibrils was detected in patients with impaired left ventricular ejection performance. This rheumatic process probably is partly responsible for the persistence of reduced ejection performance despite the improvement in preload and afterload after mitral valvuloplasty (18). All these changes indicate that a decrease in LV myocardial performance in patients with mitral stenosis is possibly caused by the inflammatory rheumatic process rather than hemodynamic parameters.

Measurement of myocardial functions via SE/SRE might be important to understand the physiological effects of valvular cardiac disease on the LV. Dray et al. (10) showed dramatic improvement after mitral balloon valvuloplasty with SE/SRE imaging method in fourteen- years- old patient with severe mitral stenosis and normal fractional shortening.

It has been shown that SRE is beneficial to determine the subclinical global dysfunction of LV long-axis and contractile reserve in asymptomatic patients with advanced mitral regurgitation (19). Through SE/SRE, Bauer et al. (20) demonstrated a

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dramatic improvement in global and regional systolic functions of the LV after percutaneous aortic valve replacement in patients with advanced aortic stenosis. Therefore, SE/SRE can be used to evaluate treatment response of the patients with cardiac valve disease.

The mitral valve is integrated with the other heart structures. The fibers at the subendocardial site array longitudinally and converge with the mitral annulus (21). Anterior mitral leaflet is bound both to the septum and the fibrous annulus of the heart and at the same time, it is a direct prolongation of the non-coronary cusp of the aortic valve. The posterior mitral valve runs along the free wall of the LV (22). Pathological events that affect the mitral valve can involve the LV functions as well. Currently, LV functions of patients with mitral stenosis are evaluated through M-mode, 2D, and Doppler echocardiography. However, it cannot detect an impairment of myocardial functions, particularly at an early phase. Despite its certain limitations, SE/SRE might be beneficial in detecting early phase myocardial function impairment. Early phase myocardial function impairment has been determined via these echocardiographic techniques in patients with amyloidosis, asymptomatic severe mitral insufficiency, end-stage chronic renal failure and morbid obesity (19, 23-25). Nevertheless, there are not enough studies regarding these methods in patients with mitral stenosis.

Doğan et al. (9) found that the PSSR and end-systolic strain values at the IVS and basal segment of the lateral LV wall were significantly lower in patients with pure mitral stenosis, who had normal ejection fraction compared to healthy subjects. In our study as well, the SE/SRE value was found to be significantly lower in the patient group compared to the control group. However, if it is considered that fibrosis primarily affects the valve, and the adjacent structures in the case of mitral stenosis, measurements only at a basal level might not be appropriate and any comment about global LV functions based on these measurements will be wrong. Therefore, in this study, the measurements were performed not only at a basal level, but also at mid and apical segments as well. Furthermore, in addition to the LV lateral-septal wall, the inferior and anterior walls were also evaluated.

Özdemir et al. (11) determined subclinical insufficiency in all of the basal segments and some of the mid segments in 60 patients with mild- moderate mitral stenosis. However, in that study, measurements were taken differently via average global longitudinal strain and strain rate imaging techniques.

Currently, there is no treatment regimen for the patients who have subclinical LV dysfunction consequent to mitral stenosis. The medical treatment of patients with mitral stenosis that do not have any complication such as pulmonary congestion and atrial fibrillation includes oral or monthly intramuscular penicillin, which is used for acute rheumatic fever prophylaxis (26). SE/SRE may provide a new opportunity for earlier treatment in those patients with systolic dysfunction even it is asymptomatic. However, a higher number of advanced studies should be performed on this subject.

Study limitations

The most significant limiting factor on SE and SRE based on Doppler imaging is the angle. During longitudinal evaluation of LV functions, the angle gradient increases from basal to apical. The amount of deformation markedly changes when the angle gradient is over 25° (27). In the present study, tissue side had to be lower than 25° and the ultrasound waves were kept as parallel as possible.

Second important limitation is presence of artifacts. Particularly, respiration and body motion of the patient decrease image quality. Therefore, measurements cannot be obtained at certain segments. In order to overcome this obstacle, measurements were performed from the images taken at the end of the expirium and including a minimum of three cycles. The total rate of segments that could not be examined in patient and control groups was 4% for SE and 8% for SRE. Moreover, intra-observer and inter-observer variables were computed 7% and 12%, respectively. These values were within acceptable ranges.

Conclusion

In conclusion, it is well known that mitral stenosis negatively affects LV functions. Our study revealed subclinical impairment of myocardial contractility via SE/SRE in patients with isolated mitral stenosis whom LVEF was within normal ranges via conventional echocardiography. SE and SRE can be used as strong indicators of LV systolic functions in either asymptomatic or minimally symptomatic patients, who do not have any sign of heart failure. In addition, SE/SRE can be used as a beneficial method to evaluate treatment initiation and patient response during this time period.

Conflict of interest: None declared.

References

1. Otto MC, Bonow RO. Valvular heart disease. In: Libby P, Bonow RO, Mann DL, Zipes DP, Braunwald E, (eds). Braunwald's Heart Disease: A Textbook of Cardiovascular Medicine. 8th ed. Philadelphia: Elsevier Saunders; p.1646-57.
2. Lee YS, Lee CP. Ultrastructural pathological study of left ventricular myocardium in patients with isolated rheumatic mitral stenosis with normal or abnormal left ventricular function. Jpn Heart J 1990; 31: 435-48.
3. Özer N, Can I, Atalar E, Sade E, Aksöyek S, Övünç K, et al. Left ventricular long-axis function is reduced in patients with rheumatic mitral stenosis. Echocardiography 2004; 21: 107-12.
4. Özdemir K, Altunkeser BB, Gök H, İçli A, Temizhan A. Analysis of the myocardial velocities in patients with mitral stenosis. J Am Soc Echocardiogr 2002; 15: 1472-8.
5. Doğan SM, Aydın M, Gürsürer M, Dursun A, Cam F, Onuk T. Early detection of cardiac function by tissue Doppler imaging in patients with mitral stenosis and sinus rhythm. Turk Kardiyol Dern Ars 2006; 34: 358-62.
6. Voigt JU, Flachskampf FA. Strain and strain rate. New and clinically relevant echo parameters of regional myocardial function. Z Kardiol 2004; 93: 249-58.

7. D'hooge J, Heimdal A, Jamal F, Kukulski T, Bijnens B, Rademakers F, et al. Regional strain and strain rate measurements by cardiac ultrasound: principles, implementation and limitations. Eur J Echocardiogr 2000; 1: 154-70.
8. Madler JF, Payne N, Wilkenshoff U, Cohen A, Derumeaux GA, Pierard LA, et al. Non-invasive diagnosis of coronary artery disease by quantitative stress echocardiography: optimal diagnostic models using off-line tissue Doppler in the MYDISE study. Eur Heart J 2003; 24: 1584-94.
9. Doğan S, Aydın M, Gürsürer M, Dursun A, Onuk T, Madak H. Prediction of subclinical left ventricular dysfunction with strain rate imaging in patients with mild to moderate rheumatic mitral stenosis. J Am Soc Echocardiogr 2006; 19: 243-8.
10. Dray N, Balaguru D, Pauliks LB. Abnormal left ventricular longitudinal wall motion in rheumatic mitral stenosis before and after balloon valvuloplasty: a strain rate imaging study Pediatr Cardiol 2008; 29: 663-6.
11. Özdemir AO, Kaya CT, Özcan OU, Özdöl C, Candemir B, Turhan S, et al. Prediction of subclinical left ventricular dysfunction with longitudinal two-dimensional strain and strain rate imaging in patients with mitral stenosis. Int J Cardiovasc Imaging 2009 Dec 5. [Epub ahead of print]
12. Sahn DJ, DeMaria A, Kisslo J, Weyman A. Recommendations regarding quantitation in M-mode echocardiography: results of a survey of echocardiographic measurements. Circulation 1978; 58: 1072-83.
13. Abraham TP, Nishimura RA. Myocardial strain: Can we finally measure contractility? J Am Coll Cardiol 2001; 37: 731-4.
14. Dubin AA, March HW, Cohn K, Selzer A. Longitudinal hemodynamic and clinical study of mitral stenosis. Circulation 1971; 44: 381-9.
15. Gordon SP, Douglas PS, Come PC, Manning WJ. Two-dimensional and Doppler echocardiographic determinants of the natural history of mitral valve narrowing in patients with rheumatic mitral stenosis: implications for follow-up. J Am Coll Cardiol 1992; 19: 968-73.
16. Otto CM: Mitral stenosis. In Otto CM (ed): Valvular Heart Disease. 2nd ed. Philadelphia, Saunders, 2004, pp 252-5.
17. Sengupta PP, Mohan JC, Mehta V, Kaul UA, Trehan VK, Arora R, et al. Effects of percutaneous mitral commissurotomy on longitudinal left ventricular dynamics in mitral stenosis: quantitative assessment by tissue velocity imaging. J Am Soc Echocardiogr 2004; 17: 824-8.
18. Lee TM, Su SF, Chen MF, Liau CS, Lee YT. Changes of left ventricular function after percutaneous balloon mitral valvuloplasty in mitral stenosis with impaired left ventricular performance. Int J Cardiol 1996; 56: 211- 5.
19. Lee R, Hanekom L, Marwick TH, Leano R, Wahi S. Prediction of subclinical left ventricular dysfunction with strain rate imaging in patients with asymptomatic severe mitral regurgitation. Am J Cardiol 2004; 94: 1333-7.
20. Bauer F, Eltchaninoff H, Tron C, Lesault PF, Agatiello C, Nercolini D, et al. Acute improvement in global and regional left ventricular systolic function after percutaneous heart valve implantation in patients with symptomatic aortic stenosis. Circulation 2004; 110: 1473-6.
21. Greenbaum RA, Ho SY, Gibson DG, Becker AE, Anderson RH. Left ventricular fiber architecture in man. Br Heart J 1981; 45: 248-63.
22. Valocik G, Kamp O, Visser AC. Three-dimensional echocardiography in mitral valve disease. Eur J Echocardiogr 2005; 6: 443-54.
23. Koyama J, Ray-Sequin PA, Falk RH. Longitudinal myocardial function assessed by tissue velocity, strain and strain rate tissue Doppler echocardiography in patients with AL(primary) cardiac amyloidosis. Circulation 2003; 107: 2446-52.
24. Govind SC, Roumina S, Brodin LA, Nowak J, Ramesh SS, Saha SK. Differing myocardial response to a single session of hemodialysis in end-stage renal disease with and without type 2 diabetes mellitus and coronary artery disease. Cardiovasc Ultrasound 2006; 4: 9.
25. Wong CY, O'Moore-Sullivan T, Leano R, Byrne N, Beller E, Marwick TH. Alterations of left ventricular myocardial characteristics associated with obesity. Circulation 2004; 110: 3081-7.
26. Dajani AS, Taubert KA, Wilson W, Bolger AF, Bayer A, Ferrieri P, et al. Prevention of bacterial endocarditis. recommendations by the American Heart Association. Circulation 1997; 96: 358-66.
27. Slordahl SA, Bjaerum S, Amundsen BH, Stoylen A, Heimdal A, Rabben SI, et al. High frame rate strain rate imaging of the interventricular septum in healthy subjects. Eur J Ultrasound 2001; 14: 149-55.