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Original Article

Assessment of left and right atrial geometrical changes in patients with stable coronary artery disease: Left and right atrial strain and strain rate imaging study

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A B S T R A C T

Objective: In patients with coronary artery disease (CAD), there are several studies that assessed the left ventricular (LV) function by strain (S) and strain rate (SR) imaging. The aim of this study is to evaluate the function of both atria in patients with CAD using strain and strain rate imaging, and to correlate this with the severity of CAD.

Methods: We conducted a prospective, single center case control study for 40 consecutive patients who presented to our department with chronic stable angina and were candidates for invasive coronary angiography. We enrolled patients from December 2013 to May 2014 and each patient was subjected to echocardiographic assessment of E/e′ of mitral valve, left atrial volume index (LAVI), right atrial volume index (RAVI), and peak atrial longitudinal strain (es) and strain rate (SR) during LV systole. This was followed by invasive coronary angiography for assessment of the severity of CAD using Gensini score. Patients were classified according to angiographic results into 3 groups: Group I (Gensini score = zero), Group II (Gensini score > 0 and < 20) and Group III (Gensini score ≥ 20).

Results: There was no statistically significant difference between the three groups in either LA volumes (V_{min}, V_{max}) and distensibility with p value of 0.272, 0.126, and 0.243 respectively or RA volumes and distensibility with a p value of 0.671, 0.183, and 0.259 respectively. On the other hand, LA & RA systolic S and SR were significantly lower among CAD patients in comparison with the group of normal coronaries. Mean LA S and SR was decreased in group III than group II (15.97 ± 3.73, 21.8 ± 6.75 % and 1.11 ± 0.30, 1.81 ± 1.23 s^{-1}) with p value of 0.005&0.041 respectively. RA systolic S and SR were significantly lower in the 2 groups with CAD than the group with normal coronaries with a p value of 0.001 and 0.002 respectively.

Conclusion: In patients with CAD and normal EF, borderline E/e′ ratio and normal atrial size, there are decreased LA and RA systolic S and SR parameters with no effect on atrial volumes or distensibility. Accordingly, this could prove that atrial wall deformation occurs early in CAD even before any changes in atrial volumes or dimensions.

1. Introduction

Coronary artery disease (CAD) is a major health problem worldwide as it carries high risk of developing heart failure, morbidity and mortality.[1] Left ventricular (LV) diastolic dysfunction is an early and sensitive marker of ischemia in patients with CAD, as it presents even before regional or global LV systolic dysfunction.[1,2] Furthermore, it is well known that the atrium has an important role in maintenance of LV stoke volume in the setting of LV dysfunction.[3] Evaluation of the LA function is emerging as an important component in assessing the effect of CAD on hemodynamics.[3] Despite its vital contribution in cardiac function, assessment of atrial function is usually neglected in our routine daily practice. During the cardiac cycle, the atria have three functions: reservoir, conduit and active contractile function.[4] Recently, several studies have shown that strain (S) and strain rates (SR)

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are powerful parameters of deformation; they directly reflect both global and regional systolic and diastolic myocardial function,[5,6] and can detect any early effects of CAD on LA functions.[7] The atrial reservoir function is reflected by systolic strain and strain rates, and the conduit and contractile functions are reflected by the early and late diastolic strain rate respectively.[8] Atrial remodeling and atrial disease are associated with major adverse cardiovascular outcomes especially atrial fibrillation, strokes and heart failure.[9,10] In this study we aimed to evaluate the function of both atria in patients with CAD using strain and strain rate imaging, and correlate this function with the severity of CAD.

2. Patients and methods

2.1. Study design and population

We conducted a prospective, single center case control study for 40 consecutive patients who presented to our department with chronic stable angina and were candidates for invasive coronary angiography. We enrolled patients from December 2013 to May 2014, Patients were classified according to the severity of CAD by coronary angiography into 3 groups; Group I with normal coronary arteries (Gensini score = zero), Group II with mild CAD (Gensini score >0 and <20) and Group III with severe CAD (Gensini score $\geq$ 20). All patients were subjected to the following, full history taking, clinical examination and routine laboratory investigations, all demographic data and risk factors of CAD were recorded; (age, sex, BMI, hypercholesterolemia (ongoing treatment of hypercholesterolemia or serum cholesterol level either fasting or non-fasting >200 mg/dl), diabetes mellitus (fasting serum glucose level >126 mg/d or diabetic medications) or current cigarette smoking.

2.2. Exclusion criteria

To minimize the effect of some medical conditions on the atrial function, we excluded the following groups of patients:elderly patients >65 y of age, Obese patients with BMI $\geq$ 30 kg/m^2, acute coronary syndrome, any history of prior coronary artery revascularization (either surgical or through percutaneous catheterization), hypertensive patients (blood pressure >140/90 or being on antihypertensive medications), diabetes mellitus, patients with EF <55%, patients presenting with heart failure symptoms, any form of valvular heart diseases, any conduction system abnormality or rhythm other than sinus rhythm, severe renal or liver dysfunction and suboptimal echocardiographic images.

2.3. Echocardiography

All patients were subjected to full echocardiographic examinations at rest, in the left lateral position using (Vivid E9 dimension; General Electric Medical Systems, Horten, Norway) equipped with 2.5-MHz variable-frequency transducer). Standard 2 D views, including, apical 4, apical 2-chamber and parasternal long-axis views were obtained and apical views were obtained also with color TDI modes. For data acquisition, 3 cardiac cycles were collected and stored in a cine-loop format, to be processed using a software (Echo Pac, GE Vivid E9 echocardiography system version 113), for off-line measurements of TDI-based strain. Simpson method were obtained for assessment of global LV systolic function, E/e′ ratio were obtained by Doppler assessment of the mitral valve, E (early diastolic peak trans mitral flow velocity) divided by e′ which was measured through colour-coded TDI of the apical 4-chamber view, using PW Doppler sample placed at the septal and lateral mitral annulus, then the average of both values was taken.[11]

1. *Calculation of Left and right atrial volume by biplane area length method:*
- LA volume = (0.85 × Area 4ch × Area 2ch)/(Longest LA length). Both the LA long axis and LA area were measured in apical 2 and apical 4 chamber views at end of ventricular systole. The LA area was obtained: by tracing the endocardial border of the atrium excluding pulmonary veins, LA appendage and sub annular plane, and LA long axis was measured as a line extending perpendicular from the back wall of LA to the mitral annular plane.[12]
- RA volume = (0.85 × area 4ch × area 4ch)/(RA length) where both RA length and RA area were measured in apical 4 chamber view at the end of ventricular systole. RA area was obtained by tracing endocardial border of the right atrium excluding tricuspid subannular plane, RA appendage, IVC and SVC), and RA long axis was measured as a line extending from back wall of RA perpendicular to the annular plane of the tricuspid valve.[13]

All atrial volumes were indexed to the body surface area (BSA). BSA is calculated by Mosteller formula: BSA (m^2) = (Height (cm) × Weight (kg)/3600)^{½}.[14]

- Calculation of LA and RA distensibility using the following formula:

$$(V_{max}) - (V_{min}) \times 100/(V_{min}).$$

(V_{max}) = maximal volume of the atrium at the end of the systole (T wave on ECG) & (V_{min}) = minimum volume of the atrium at the end of the diastole (R wave on ECG).[12]

2. *Strain and strain rate imaging of the left and right atrium:*
2D color-coded Tissue Doppler imaging (TDI), using standard apical 4 & apical 2 chamber views, at a high frame rate (>180 fps) and the narrowest possible sector angel possible (30°) images were be stored for off-line analysis using Echo Pac, GE 113, Atrial longitudinal systolic Strain S and SR were measured by placing a 2 mm sample volume (because of thin atrial wall) at the mid segment of : the LA septal wall, LA lateral wall, RA free wall (using the apical 4 chamber view), and LA inferior wall and LA anterior wall (using the apical 2 chamber view).[15,16] The studied segments were kept at the center of the U/S sector to insure the accuracy, and strain S /SR velocity curves were obtained and analyzed offline with dedicated software, atrial reservoir function during ventricular systole, represented by the interval between mitral valve closure (MVC) and mitral valve opening (MVO), peak positive systolic strain and strain rate were calculated from the extracted curves over 3 recorded cardiac cycles to obtain mean strain and strain rate values of the studied segment.[17]

2.4. Coronary angiography

Diagnostic coronary angiography was done to all patients through either femoral or radial approach according to local protocol. Gensini score was used to assess the severity of CAD by an experienced cardiologist, blinded to the echocardiographic data of the patients. Gensini score was calculated through multiplication of score used for grading the luminal narrowing of the main coronary artery by a factor which takes into account the site and importance of the lesion. The score of luminal narrowing was 1 for $\leq$25% stenosis, 2 for 26–50% stenosis, 4 for 51–75% stenosis, 8 for 76–90% stenosis, 16 for 91–99% stenosis and 32 for total occlusion. The factor of location was 5 for left main, 2.5 for the proximal lesion of either LAD (left anterior descending) or LCX (left circumflex), 1.5 for mid lesion, 1 for distal LAD, mid-distal LCX or RCA (right coronary artery). Then the sum of scores of all coronary arteries was used to express the total Gensini score.[18]

2.5. Statistical analysis

SPSS software version 20 was used for statistical analysis. The data were analyzed using Student's t-test and the numeric data were expressed as the mean ± SD. Categorical data were analyzed with a $\times 2$ test, and the results were expressed in percentages. ANOVA test was used for comparison among different times in the same group in quantitative data. Chi-square test was used for comparison between two groups as regards qualitative data. $P < 0.05$ was considered statistically significant.

3. Results

The 3 groups included 10 patients with Gensini score = 0 (group I), 15 patients with Gensini score < 20 (group II) and 15 patients with Gensini score ≥ 20 (group III). Demographic data of group III (mean age: 51.0 + 6.81 years, 10 (66.7 %) males, 9 (60%) smokers); In group II (mean age: 49.53 + 7.12 years, 11 (73.3%) males, 10 (66.7%) smokers, and in group I (mean age:46.40 + 9.59 years, 6 (60%) males, 8 (80%) non-smokers), CAD patients had significantly higher total cholesterol level than the group with normal coronaries (p1 = 0.001, p2 = 0.001) where p1; between group I& II and p2; between group I& III. Also it was found that patients in group III have significantly higher LDL levels than group II (p3 = 0.028) where p3; between group II& III (Table1).

3.1. Echocardiographic measurements: (Table 2)

As regard LV function, EF% values have no statistically significant difference in the three studied groups, the value of E/e′ in the 2 CAD groups was higher than the control group, but the differences didn't reach statistical significance. E/e′ ratio was in the gray zone (between 5 to 13) representing that there were no significant increase in LV diastolic filling pressure in the three groups, None were found to have E/e′ > 15 (cut off value >15 represent elevated LV filling pressure (LVFP).[11] LA volumes (LA V_{min}, LA V_{max}) in the two groups having CAD were higher than group I but they didn't reach statistically significant difference (p value = 0.272, 0.126) respectively. There was no statistically significant difference between the three groups as regard LA diameter (p value = 0.986) nor LA distensibility (p = 0.243). There was no statistically significant difference between the three groups regarding RA volumes (RA V_{min}, RA V_{max}) and RA distensibility (Table 2).

3.2. Deformation analysis

As shown in Table 3, Mean LA S &SR showed decreased trend among CAD patients which was less than normal coronary group, also it was found that (LA S&SR) measures correlated negatively with the severity of the CAD (as it was decreased more in patients with Gensini score ≥ 20 than patients with Gensini score < 20). Mean left atrial strain was higher in group I than group II & III. There was statistically significant difference between group I and II (p1 = 0.001), between group I and III (p2 = 0.001) & between group II & III (p3 = 0.005). Mean LA strain rate was higher in group I than group II & III, its average values in group I, II and III were (2.95 + 0.63, 1.81 + 1.23, 1.11 + 0.30) respectively, with statistically significant difference between group I & II (p1 = 0.002), between group I & III (p2 = 0.001), also between group II & III (p3 = 0.041). Mean RA strain was higher in group I than group II and III showing statistically significant difference between group I and II (p1 = 0.001) & between group I and III (p2 = 0.001), but there was no statistically significant difference between group II & III (p3 = 0.083) (Fig. 1). Mean RA SR was higher in group I than group II & III showing statistically significant difference between group I & II (p1 = 0.001), &between group I and group III (p2 = 0.001). But there was no statistically significant difference between group II & III (p3 = 0.748).

4. Discussion

The atrium has an important role in the overall cardiac function as it is acting as a reservoir during LV systole, conduit during early LV diastole, and a booster pump in late diastole, sharing by up to

Table 1
Baseline and demographic characteristics.

	Group I	Group II	Group III	P value	P1	P2	P3
Age	46.40 + 9.59	49.53 + 7.12	51.0 + 6.81	0.349	0.325	0.151	0.605
Gender (M/F) (%)	6/4 (60/40%)	11/4 (73.3/26.7%	10/5 (66.7/33.3%)	–	–	–	–
BMI	24.6 + 1.77	25.4 + 1.99	25.43 + 2.16	0 0.542	00.335	0.316	00.964
Smoking N (%)	2/8(20/80%)	10/5 (66.7/33.3)	9/6 (60/40)	–	–	–	–
LDL	97 ± 8.89	133. ± 16.5	144.7 ± 13.7	0.001	0.001	0.001	0.028
HDL	50.8 ± 7.8	48.8 ± 2.9	44.3 ± 7.8	0.213	0.618	0.101	0.196
T. Cholesterol	159.3 ± 10.8	216.6 ± 41	221.6 ± 20.34	0.001	0.001	0.001	0.636

LDL = low-density lipoprotein; HDL = high-density lipoprotein; T. cholesterol = total cholesterol; BMI = body mass index; p1; between group I and II, p2; between group I & III and p3; between group II & III. Significant p < 0.05.

Table 2
Echocardiographic data of the studied groups.

	Group I	Group II	Group III	P. value	P1	P2	P3
E/e	7.27 ± 1.35	9.09 ± 2.5	8.63 ± 2.6	0.162	0.062	0.161	0.585
EF%	67.3 ± 3.56	63.1 ± 6.28	62.67 ± 7.21	0.153	0.10	0.072	0.859
LA diameter (cm)	3.37 ± 0.34	3.39 ± 0.36	3.38 ± 0.34	0.986	0.870	0.944	0.917
LA V_{max}/BSA	22.31 ± 3.36	27.46 ± 8.30	27.31 ± 6.34	0.126	0.065	0.073	0.950
LA V_{min}/BSA	11.77 ± 3.22	14.5 ± 6.81	15.86 ± 6.77	0.272	0.281	0.110	0.546
LA distensibility:	130.2 ± 52.5	102.6 ± 50.02	97.4 ± 45.29	0.243	0.175	0.109	0.774
RA V_{max}/BSA	17.2 ± 5.39	20.8 ± 6.45	22.23 ± 7.45	0.183	0.186	0.070	0.568
RA V_{min}/BSA	9.57 ± 2.87	10.61 ± 3.36	10.57 ± 2.99	0.671	0.420	0.435	0.977
RA distensibility:	82.05 ± 40.85	98.54 ± 44.82	105.53 ± 58.03	0.259	0.419	0.105	0.353

EF% = ejection fraction, LA = left atrium; RA = right atrium; V_{max} = maximum volume; V_{min} = minimum volume, BSA = body surface area; p1; between group I & II, p2; between group I & III and p3; between group II & III. Significant p < 0.05.

Table 3
deformation analysis of the studied groups.

	Group I	Group II	Group III	P value	P1	P2	P3
Mean LA S (%)	36.9 + 5.37	21.8 + 6.75	15.97 + 3.73	0.001	0.001	0.001	0.005
Mean LA SR (s^{-1})	2.95 + 0.63	1.81 + 1.23	1.11 + 0.30	0.001	0.002	0.001	0.041
LA lateral							
S (%)	39.88 + 10.18	20.41 + 12.92	15.76 + 6.1	0.001	0.001	0.001	0.216
SR (s^{-1})	3.96 + 1.59	1.64 + 1.52	1.4 + 0.53	0.001	0.001	0.001	0.611
LA anterior							
S (%)	32.89 + 12.43	20.5 + 10.2	16.0 + 7.97	0.001	0.005	0.001	0.227
SR (s^{-1})	2.95 + 1.25	2.1 + 1.7	1.12 + 0.45	0.005	0.115	0.001	0.044
LA inferior							
S (%)	47.9 + 15.1	26.3 + 14.5	19.1 + 8.1	0.001	0.001	0.001	0.126
SR (s^{-1})	2.26 + 0.59	1.58 + 0.80	1.19 + 0.46	0.001	0.014	0.001	0.097
LA septum							
S (%)	26.96 + 11.91	20.15 + 6.58	13.1 + 4.64	0.001	0.036	0.001	0.016
SR (s^{-1})	2.64 + 1.02	1.92 + 1.28	1.44 + 0.45	0.017	0.077	0.005	0.185
Mean RA S (%)	44.63 + 14.1	23.26 + 6.58	17.75 + 4.3	0.001	0.001	0.001	0.083
Mean RA SR (s^{-1})	4.07 + 1.92	1.86 + 0.86	2.04 + 1.75	0.002	0.001	0.002	0.748
RA lateral							
S (%)	62.3 + 27.26	27.95 + 11.40	22.43 + 9.76	0.001	0.001	0.001	0.361
SR (s^{-1})	5.6 + 2.99	1.82 + 0.89	1.57 + 0.65	0.001	0.001	0.001	0.684

LA = left atrium; RA = right atrium; S = strain; SR = strain rate; p1; between group I & II, p2; between group I & III and p3; between group II & III. Significant $p < 0.05$.

30% of LV stroke volume in normal subjects.[19] In CAD, the atrial function could be primarily or secondarily affected. Assessment of LA and RA function may serve as an important component in the evaluation hemodynamic effects of CAD.[20,21]

In the present study most of CAD patients were found to have elevated total cholesterol & LDL levels, also majority of CAD patients were smokers while in the group of patients with normal coronary angiography, only 20% were smokers. E/e′ was in the gray zone (between 5 to 13) representing that there were no significant increase in LV diastolic filling pressure in the three groups, none were found to have E/e′ > 15 (cut off value >15 represent elevated LV filling pressure (LVFP) and this might minimize the effect of elevated LVEDP on atrial function.

There was no statistically significant difference between the three groups as regard LA and RA volumes and distensibility, all had normal LA dimension. On the other hand, patients with CAD had decreased LA and RA systolic strain (S) and strain rate (SR) measurements than the group with normal coronaries. Also the present study showed negative relation between LAs S (peak LA systolic strain) & LA s SR (peak LA strain rate) and the severity of CAD.

In the present study, there was no statistically significant difference in LV EF % between the 3 groups, furthermore the present study found that LA volumes (LA V_{min}, LA V_{max}) in the two groups having CAD were higher than group I but they didn't reach statistically significant difference. As regard to LA dimension, there was no statistically significant difference between the three groups; these results come in agreement with (Ping Yan et al.).[22] Also it comes in agreement with (Liu Y, et al.)[23] who evaluated LA function in patients with CAD, using conventional echocardiographic and 2D strain and strain rate parameters; their results revealed no statistically significant difference between control and CAD with normal LA dimension groups as regard to LA volumes and this comes in agreement with the current study. Meanwhile there was statistically significant increase in LA volumes in CAD with enlarged LA group than control group and this is not in agreement with the results of the current study.

On the other hand as regard to LA volumes the results of the current study are not in agreement with (Yu M.C et al.)[24] who found that there is increase in LA cavity dimensions and LA volumes in CAD patients than control group with statistically significant difference between the two groups.

In the present study there was no statistically significant difference between the three groups as regard RA volumes (RA V_{min}, RA V_{max}) and this is in agreement with (Yu M.C et al.)[24] results that showed no significant difference between CAD patients and control group as regard to RA volumes.

In the present study, E/e′ was used together with LA distensibility to assess LV filling pressure (LVFP) aiming to study its impact on LA function. As regard to E/e′, we found that the 2 CAD groups had higher E/e′ ratio when compared to the group with normal coronaries, but didn't reach statistically significant difference; this is in agreement with (Ping Yan et al.).[22] Furthermore and as regard to E/e′, the result of the present study is not concordant with (Tsai et al.)[25] who studied the diagnostic value of segmental longitudinal strain in coronary artery disease without left ventricular dysfunction; they used tissue Doppler to obtain septal e′, they found higher E/e′ ratio in CAD patients with preserved EF % than control group.

As regard LA distensibility, results of the present study revealed no significant difference between the three groups, although there was no significant decrease in LA distensibility in CAD groups compared to group I and this is comparable with the results of Hsiao SH et al.[26] In their study, E/e′ was higher in multiple vessel group than single vessel groups and LA distensibility was lower in multiple vessel group than single vessel group, and they found that E/e′ is not completely satisfactory for assessing LVFP in patients with stable angina; especially those with single-vessel disease & preserved systolic function, average e′ was not superior to any regional e′ for assessing LVFP by the E/e′ method, and For identifying high LVFP in CAD patients, LA distensibility is better than E/e′.[26]

In the present study, LA systolic strain (S) and strain rate (SR) measures show statistically significant difference between the three groups, S& SR values were decreased in CAD groups compared to the group with normal coronaries, and this result comes in agreement with (Liu et al.)[24], they found statistically significant decrease in LA systolic S and SR measures in patients with CAD compared to control group. This study concluded that, LA reservoir function in patients with CAD is impaired, even in the absence of LA enlargement.

Also this result comes in agreement with (Guan et al.)[27] who studied the association of left atrial myocardial function with left ventricular diastolic dysfunction in subjects with preserved EF using strain and strain rate parameters. They enrolled 95 patients with different stages of LV diastolic dysfunction and 29 normal

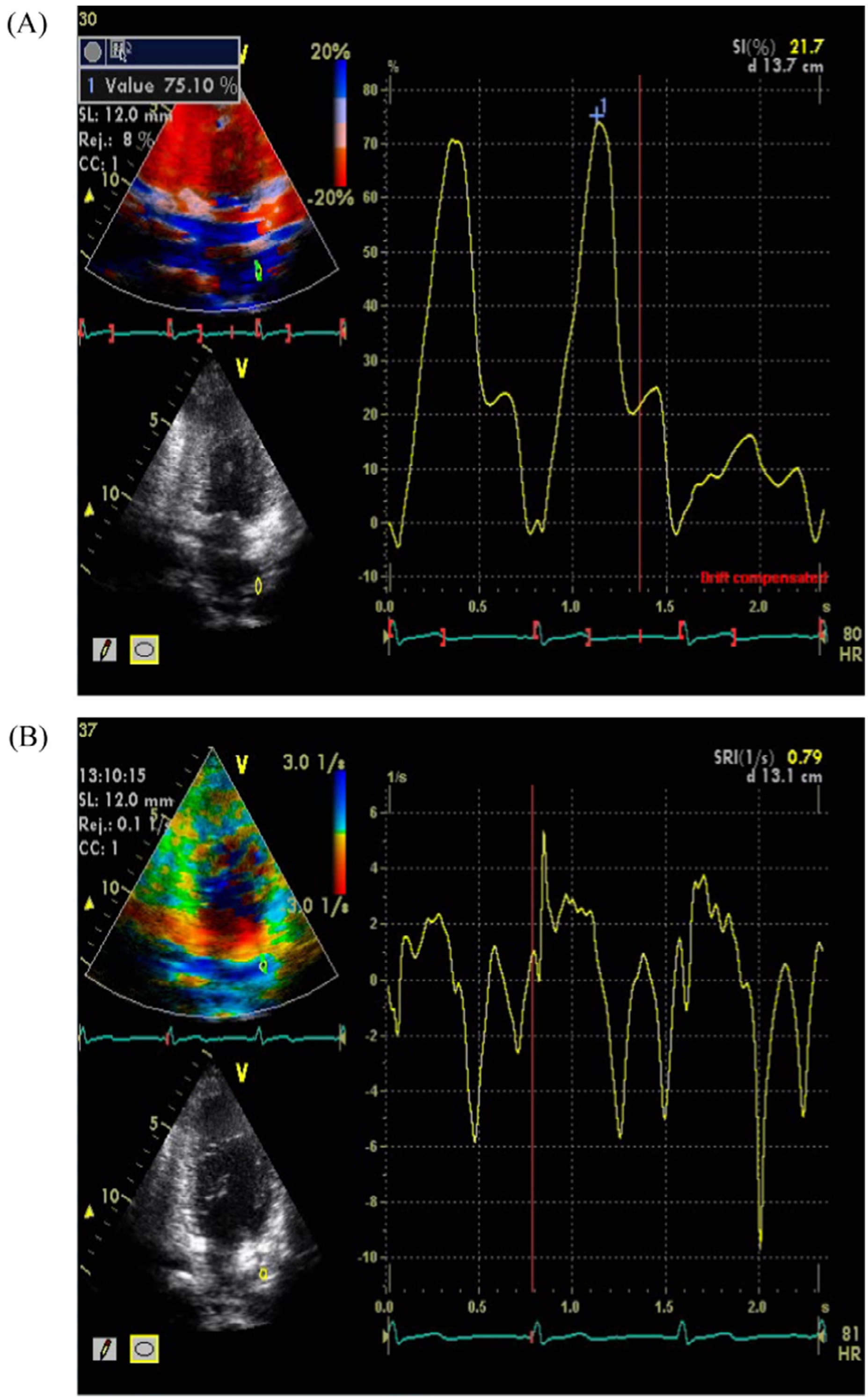

Fig. 1. Assessment of regional atrial myocardial function by tissue Doppler imaging. The sample volume was placed at the mid-level of left atrial anterior free wall on color tissue Doppler image to reconstitute the strain (A), and strain rate (B) curves.

subjects as control group; they found that atrial S and SR measures were reduced in patients with mild and moderate diastolic dysfunction with E/e′ in the gray zone (10.2 ± 2.1 and 12.1 ± 1.8) to a degree less than control group, with no change in atrial volumes or dimensions.

Furthermore, as regard to LA strain and strain rate measures, the present study found that LA peak systolic strain and stain rate parameters were decreased in group III more than group II with statistically significant difference giving negative relationship between the severity of CAD and LA systolic S and SR; this result comes in disagreement with Ping Yan et al.[22]; as they found that there was no significant difference between group with mild CAD and those with severe CAD as regard to S and SR measures, although in the same study LA S and SR showed decreased trend among CAD patients but didn't reach statistical significance when compared with control group and this also is not in agreement with the present study[22] This disagreement may be explained by the difference in the exclusion criteria as they enrolled diabetic and hypertensive patients in their study while we excluded them and this may be important causes other than ischemia in affection of LV diastolic function with subsequent impact on LA function.

As regard to RA systolic S and SR measures, the present study showed statistically significant difference between CAD groups and group of normal coronaries, as CAD groups showed lower S and SR values, but between group II & III (CAD patients) there was no significant difference, and this is not in agreement with Ping Yan et al.[22]; their results revealed no significant difference between control, and 2 CAD groups or even between 2CAD groups as regard to RA S & SR measurements. This could be explained as they used speckle tracking method while we used colored tissue Doppler to obtain S and SR measures. Also we didn't stratify our patients according to the distribution pattern of the affected vessels, so may be the majority of the CAD patients, in the present study, had LCX and RCA occlusions that affect right atrial deformation measures through right atrial ischemia.

5. Conclusions

In patients with chronic stable CAD and normal LA size, normal EF and borderline E/e′, LA and RA systolic S and SR parameters are significantly decreased despite no differences in atrial volumes or distensibility. This proves that atrial wall deformation occurs early in CAD even before any change in atrial volumes or dimensions. Strain and strain rate echocardiographic imaging for both atria are not only sensitive markers for early detection of ischemia, but also they may be used for the detection of severity of CAD. A study with more sample size may be needed to confirm these results.

Conflict of interest

None declared.

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