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The AutoStrain LV technique is a sensitive method for detecting subclinical left ventricular dysfunction in patients with obstructive sleep apnea syndrome

Yi Zhang, MS[a], Shangyong Zhu, MS[a,*]

Abstract

Obstructive sleep apnea syndrome (OSAS) is strongly associated with multiple cardiovascular diseases, however, early detection of subclinical myocardial damage is a challenge. We aimed to compare the sensitivity of AutoStrain LV technology versus conventional echocardiography for assessing left ventricular (LV) impairment in patients with subclinical OSAS and to identify sensitive echocardiographic indicators of LV injury. Classifying 126 qualified participants based on their apnea–hypopnea index (AHI), we formed control, mild, moderate, and severe OSAS categories. LV global longitudinal strain (LVGLS) was evaluated by AutoStrain LV technique. Conventional two-dimensional echocardiography was used to measure different factors including LV end-diastolic diameter, LV end-systolic diameter, interventricular septum diameter, LV posterior wall diameter, and LV functional shortening. LV ejection fraction was calculated by modified biplane Simpson method, and the Doppler ultrasound was used to measure the LV diastolic function indices E/A and E/E′. We calculated the correlations between these ultrasound parameters and the AHI. Although LV ejection fraction and LV functional shortening are normal, the LVGLS in the OSAS group decreased with the severity of the disease ($P < .001$). The values of E/A in the mild, moderate, and severe OSAS groups, as well as the values of E/E′ in the mild and severe OSAS groups, showed significant differences compared to the control group, but no significant differences were found between different OSAS subgroups. The IVST and LVPWT values in the moderate and severe OSAS groups were higher than those in the control group and mild OSAS group, but there were no significant differences between the other groups. Conventional echocardiographic parameters did not change with the severity of the disease. Correlation analysis showed that LVGLS had the strongest correlation with AHI ($r = -0.732$, $P < .001$). Compared with conventional echocardiography, AutoStrain LV technology has a higher sensitivity for monitoring LV function impairment in patients with subclinical OSAS.

Abbreviations: AHI = apnea–hypopnea index, AI = artificial intelligence, ICC = intraclass correlation coefficient, LV = left ventricular, LVEF = left ventricular ejection fraction, LVESD = left ventricular end-systolic diameter, LVFS = left ventricular functional shortening, LVGLS = left ventricular global longitudinal strain, OSAS = obstructive sleep apnea syndrome, PSG = polysomnography, STE = speckle tracking echocardiography.

Keywords: AutoStrain LV, left ventricular global longitudinal strain, obstructive sleep apnea syndrome, subclinical left ventricular dysfunction

1. Introduction

Obstructive sleep apnea syndrome (OSAS) is a common disorder characterized by intermittent hypoxia and episodes of breathing cessation during sleep.[1] It is associated with various cardiovascular diseases, including hypertension, coronary artery disease, heart failure, arrhythmias, and atrial fibrillation.[2–4] Untreated OSAS significantly increases the risk of developing cardiovascular diseases and overall mortality.[5,6] Currently, there is a shortage of safe and effective medications for OSAS. Continuous positive airway pressure therapy is the primary treatment for OSAS, however, due to poor patient compliance, the therapeutic effect is limited.[7–9] Therefore, early detection of subclinical cardiovascular damage caused by OSAS is of paramount importance.

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The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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Currently, there is a lack of ideal monitoring methods for the early detection of subclinical myocardial injury. Endocardial myocardial biopsy is considered the most accurate method for diagnosing myocardial injury, with high specificity and sensitivity. Due to the need for invasive puncture, risk and high technical requirements, this technique is difficult to perform widely.[10] Cardiovascular magnetic resonance imaging is an ideal method for detecting subclinical cardiomyopathy due to its noninvasive and highly specific characteristics, however, its high cost limits its clinical application.[11] Multigated radionuclide angiography can be used to assess the ejection fraction and local ventricular wall systolic and diastolic function, but it involves the use of radiation, has low spatial resolution, and is insensitive to subclinical myocardial damage.[12] Echocardiography is the most commonly used noninvasive technique for assessing cardiac function due to its advantages, including being noninvasive, simple to perform, and capable of providing dynamic and real-time imaging. However, traditional methods have certain limitations. Until now, there has been no agreement among studies regarding the left ventricular (LV) structure and function in patients with OSAS, and the specific echocardiographic parameters that can detect early LV dysfunction in these patients have not been well established.

Speckle tracking echocardiography (STE) is regarded as a sensitive method for evaluating subclinical cardiac function.[13] The basic principle is to track myocardial deformation in real-time and comprehensively evaluate the mechanical process of myocardial contraction. Independent of geometric assumptions, STE is more sensitive than LV ejection fraction (LVEF) in assessing cardiac dysfunction and can provide additional prognostic information.[14–16] AutoStrain technology is a new technology based on the combination of two-dimensional STE and artificial intelligence (AI), which can perform tasks automatically, so as to automatically quantify myocardial strain simply, quickly and accurately, minimize the influence of operator dependence and subjectivity, and has good repeatability and consistency. Currently, there have been reports on the use of AutoStrain technique,[17,18] but no studies have been conducted to evaluate cardiac function in OSAS patients.

In this study, we aimed to compare the sensitivity of AutoStrain LV technique to conventional echocardiography in assessing early LV function impairment in subclinical OSAS patients with normal ejection fraction, and to explore the potential of AutoStrain LV technique in detecting early myocardial injury.

2. Methods

2.1. Study design and participants

Our study protocol was approved by the Institutional Ethics Committee, and written informed consent was obtained from all participants. From March 2022 to October 2023, patients newly diagnosed with OSAS were recruited at the Sleep Monitoring Center of the First Affiliated Hospital of Guangxi Medical University, Nanning, China. Healthy volunteers were concurrently enrolled as a control group.

All participants underwent a full overnight polysomnography (PSG) examination. An apnea or hypopnea event was defined as occurring when airflow was completely obstructed for more than 10 seconds or when respiratory airflow was reduced by 50% and oxygen saturation (SaO_2) decreased by 3% for more than 10 seconds. The apnea–hypopnea index (AHI) was calculated as the average number of apnea and hypopnea episodes per hour of sleep.[19] Based on the AHI values, participants were classified into the following groups: control group (AHI < 5 events/h), mild OSAS group (AHI = 5–15 events/h), moderate OSAS group (AHI = 15–29.9 events/h), and severe OSAS group (AHI ≥ 30 events/h).

The inclusion criteria for participants were: EF ≥ 50%, good overall health, sinus rhythm, and successful PSG monitoring. Exclusion criteria included diabetes, hypertension, cardiovascular diseases (such as congenital heart disease, moderate to severe valvular disease, coronary artery disease, and heart failure), central obstructive sleep apnea, pulmonary diseases (such as lung infections, chronic obstructive pulmonary disease, and interstitial lung disease), liver and kidney diseases, history of stroke, malignancies, and other life-threatening conditions. Participants with incomplete or poor-quality PSG or echocardiographic data were also excluded.

Ultimately, 126 participants were included in the study, consisting of 30 mild OSAS patients, 30 moderate OSAS patients, 36 severe OSAS patients, and 30 healthy controls matched for gender and age, as shown in Figure 1.

2.2. Conventional echocardiography

Transthoracic echocardiographic examinations were performed using the Philips EPIQ 7C ultrasound diagnostic system, with S5-1 and X5-1 probes, operating at frequencies ranging from 1 to 5 MHz. The echocardiographic examination methods and standards were conducted according to the guidelines of the American Society of Echocardiography (ASE).[20] An expert with over 10 years of experience in echocardiography, blinded to the patients' clinical and sleep data, measured each parameter. Each parameter was measured 3 times, and the average value was recorded.

In the LV long-axis view, M-mode ultrasound was used to measure the LV end-diastolic diameter, LV end-systolic diameter, interventricular septal thickness (IVST), and LV posterior wall thickness (LVPWT), and to record the LV fractional shortening (LVFS). LVEF was measured using the modified biplane Simpson method. In the apical 4-chamber view, pulsed Doppler was used to measure the peak early diastolic flow velocity (E) and late diastolic flow velocity (A) at the mitral valve. The E/A ratio was calculated by dividing the E velocity by the A velocity. Tissue Doppler imaging was employed to assess the early diastolic myocardial velocity at the septal and lateral mitral annulus, and the average value of the 2 measurements was taken as the E′ value. The E/E′ ratio was calculated by dividing the E velocity by the mean E′ value.

2.3. AutoStrain LV imaging

All subjects were positioned in the left lateral decubitus position, with an electrocardiogram connected for monitoring. Under 2D imaging conditions, the frame rate was set to 60 to 80 frames per second, and the image quality was optimized. Dynamic images of the apical 4-chamber, 3-chamber, and 2-chamber views were continuously acquired for 4 cardiac cycles and stored in DICOM format for subsequent analysis.

The online analysis process using the software was as follows: The acquired dynamic images of the apical 4-chamber, 3-chamber, and 2-chamber views were imported into the TomTec Imaging software. The "LV auto strain" option was selected, and the software automatically tracked the endocardial borders and calculated the LV global longitudinal strain (LVGLS) value (Fig. 2). If the endocardial border tracking was suboptimal, manual adjustment was performed to ensure complete tracking of the endocardial surface. Cases with poor tracking of more than 2 myocardial segments were excluded from LVGLS analysis. To avoid confusion, the LVGLS values for all patients were presented as absolute values.

2.4. Consistency check

Images from 20 patients were randomly selected, and LVGLS measurements were repeated by the same observer after 1

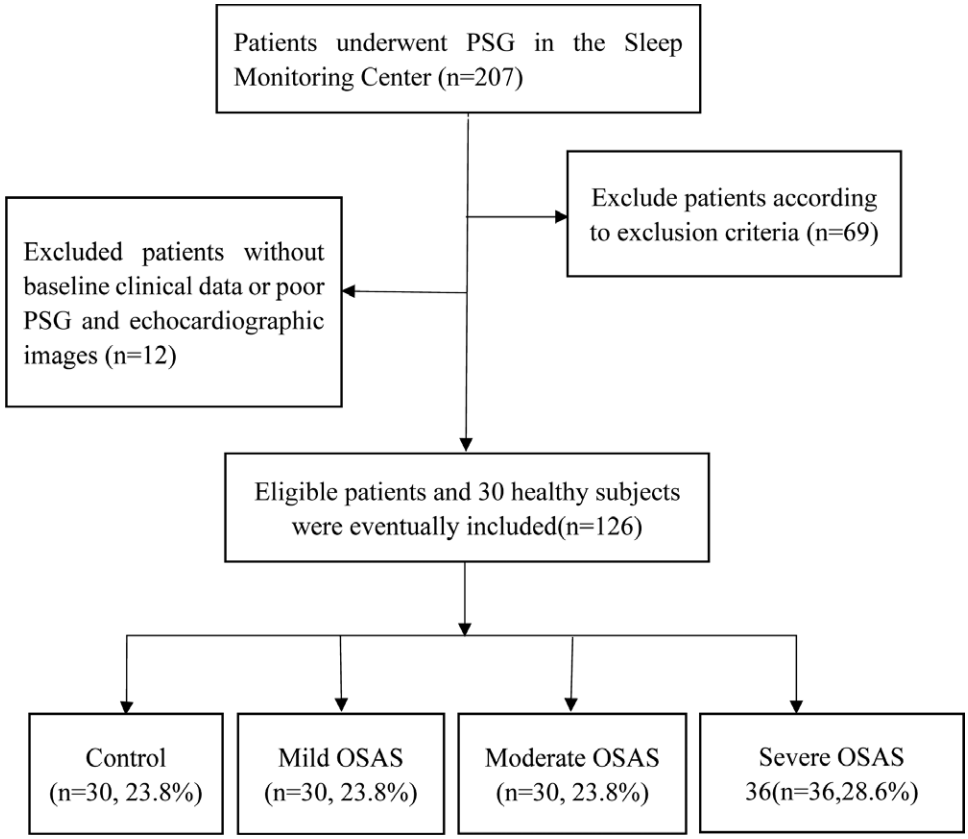

Figure 1. Study flowchart. PSG = polysomnography, OSAS = obstructive sleep apnea syndrome.

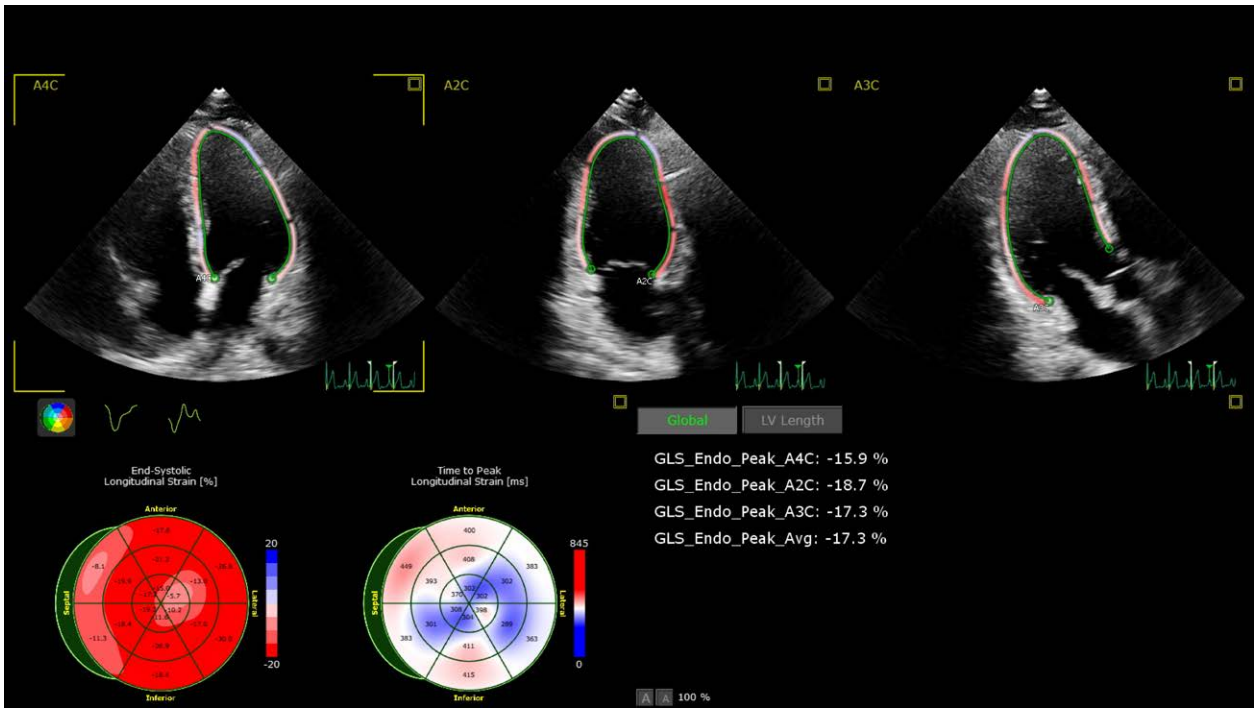

Figure 2. LVGLS measured by the AutoStrain LV technique. LVGLS = left ventricular global longitudinal strain.

month to assess intraobserver agreement, and by another observer to assess interobserver agreement. The Bland–Altman method was used to evaluate both inter- and intraobserver variability, and the intraclass correlation coefficient (ICC) was calculated.

2.5. Statistical analysis

Statistical analyses were conducted using SPSS (version 24.0, IBM, Armonk, NY). Before analysis, the normality of all continuous variables was assessed using the Kolmogorov–Smirnov

test. Normally distributed data are presented as means ± standard deviation, while non-normally distributed data are expressed as medians with interquartile ranges. Categorical variables are reported as frequencies (percentages). To compare the data across the 4 groups, one-way analysis of variance (ANOVA) or the Kruskal–Wallis H test was applied, depending on the data distribution. Spearman rank correlation was used to examine the relationship between echocardiographic parameters and the AHI. Statistical significance was set at $P < .05$.

3. Results

3.1. Basic information of the subjects

Compared to the control and mild OSAS groups, the moderate and severe OSAS groups had higher body mass index, with no significant differences between the moderate and severe groups. Additionally, the severe OSAS group had higher systolic blood pressure than both the control and mild groups, while no significant differences were observed between the other groups. There were no significant differences in age, sex, heart rate, or diastolic blood pressure among the groups (Table 1).

3.2. Conventional echocardiography

Regarding systolic function parameters, no significant differences were observed in LVEF and LVFS between the OSAS and control groups. Similarly, there were no significant differences in two-dimensional parameters, such as LV end-systolic diameter and LV end-systolic volume, between the 2 groups.

In terms of diastolic function, the E/A ratio was significantly lower in the mild, moderate, and severe OSAS groups compared to the control group ($P < .001$). However, no significant differences were observed among the OSAS subgroups. The E/E′ ratio was higher in both the mild and severe OSAS groups compared to the control group ($P = .04$), but no significant differences were found between the moderate OSAS group and either the control or other OSAS subgroups.

Furthermore, the IVST and LVPWT measurements were significantly higher in the moderate and severe OSAS groups compared to the control and mild OSAS groups ($P < .001$), with no significant differences observed between the other groups. These conventional parameters did not show any variation with the severity of OSAS (Table 2).

3.3. AutoStrain LV imaging

The LVGLS values in the control, mild OSAS, moderate OSAS, and severe OSAS groups were 20.5 ± 1.1%, 19.8 ± 2%, 18.2 ± 1.4%, and 15.9 ± 1.4%, respectively ($P < .001$). LVGLS was significantly reduced in the moderate and severe OSAS groups, with a progressive decline observed as the severity of the disease increased (Table 3).

3.4. Correlation analysis of ultrasound parameters with OSAS severity

The LV ultrasound parameters exhibited varying correlations with the AHI, with LVGLS showing the strongest correlation ($r = -0.732$, $P < .001$) (Table 4).

3.5. Consistency check

A consistency check was performed on the ICC for LVGLS, evaluated from a cohort of 20 consecutive patients, demonstrating remarkable interrater reliability (ICC: 0.990, 95% CI: 0.998–1.000) and notable inter-group reliability (ICC: 0.980, 95% CI: 0.956–0.993). The detailed data are presented in Figure 3.

4. Discussion

This study is the first to apply the AI-based AutoStrain LV technique to assess LV function in OSAS patients. Our results show that LVGLS decreases as the severity of OSAS increases. Additionally, we found a strong correlation between LVGLS and OSAS severity. Compared to traditional echocardiography, the AutoStrain technique demonstrated higher sensitivity, making it a promising tool for detecting early cardiac dysfunction in subclinical OSAS patients.

Our study found that commonly used echocardiographic indicators of LV systolic function, such as LVEF and LVFS, did not show significant abnormalities in the OSAS group. Although statistically significant differences in IVST and LVPWT were observed between the moderate and severe OSAS groups compared to the control and mild OSAS groups, no significant differences were found between the moderate and severe OSAS groups. LVEF is the most commonly used clinical parameter for assessing LV systolic function, and the modified biplane Simpson method is the standard technique for its measurement. However, this method has limitations. It relies on geometric assumptions and requires manual delineation of the endocardial border, which may lead to issues such as foreshortening at the apex, unclear endocardial borders, and inaccuracies in tracing the endocardium. Additionally, the method is highly examiner-dependent, which may introduce subjective bias and result in inaccurate EF measurements. In contrast, LVGLS was significantly reduced in the moderate and severe OSAS groups, with a further decline as disease severity increased. These findings suggest that LVGLS is more sensitive than conventional

Table 1

General information of all subjects.

Variables	Control (n = 30)	Mild OSAS (n = 30)	Moderate OSAS (n = 30)	Severe OSAS (n = 36)	*P* value
Age (yr)	41.1 ± 7.2	41.0 ± 11.5	42.4 ± 9.9	44.2 ± 10.4	.53
Males, n (%)	23 (76.7%)	23 (76.7%)	24 (80%)	27 (75%)	.97
BMI (kg/m^2)	24.4 ± 2.7	24.5 ± 3.1	26.8 ± 3.4*,†	27.4 ± 2.8*,†	<.001
HR (bpm)	70.3 ± 3.0	71.7 ± 2.7	71.5 ± 2.5	71.4 ± 2.4	.18
SBP (mm Hg)	117 ± 4.8	117.9 ± 7.4	119.9 ± 6.5	121.9 ± 5.8*,†	.01
DBP (mm Hg)	77.3 ± 2.7	74.4 ± 5.6	79.5 ± 4.6	78.6 ± 4.3	.45
AHI (events/h)	1.7 (0.5, 2.8)	9.6 (7.2, 11.8)*	22.9 (18.2, 24.8)*,†	52.1 (46.7, 71.4)*,†,‡	<.001

AHI = apnea–hypopnea index, BMI = body mass index, DBP = diastolic blood pressure, HR = heart rates, OSAS = obstructive sleep apnea syndrome, SBP = systolic blood pressure.

*$P < .05$ versus control group.

†$P < .05$ versus mild OSAS group.

‡$P < .05$ versus moderate OSAS group.

Table 2

The comparison of left ventricular conventional structure and function parameters in different groups.

Variables	Control (n = 30)	Mild OSAS (n = 30)	Moderate OSAS (n = 30)	Severe OSAS (n = 36)	*P* value
LVFS (%)	36.4 ± 4.3	38.2 ± 4.1	39.3 ± 3.8	38.7 ± 6.4	.12
LVEF (%)	66.1 ± 5.7	68.2 ± 5.1	69.7 ± 4.9	68.7 ± 7.3	.11
LVEDD (mm)	45.2 ± 3.8	46.1 ± 4.3	45.4 ± 3.4	47.9 ± 4.4*,‡	.03
LVESD (mm)	28.9 ± 2.9	28.5 ± 3.1	27.7 ± 2.8	29.2 ± 3.4	.27
LVESV (mL)	31.8 ± 7.6	31.7 ± 9.6	28.6 ± 6.8	33.4 ± 9.4	.16
LVEDV (mL)	94.2 ± 8.3	98.6 ± 21.8	94.7 ± 17.3	107.7 ± 22.7*,‡	.03
IVSD (mm)	8.9 ± 0.9	8.8 ± 1.4	9.9 ± 1.1*,†	10.4 ± 1.0*,†	<.001
LVPWTD (mm)	9.0 ± 0.9	8.8 ± 1.4	10.4 ± 1.4*,†	10.2 ± 1.4*,†	<.001
E/A	1.5 ± 0.3	1.1 ± 0.3*	1.0 ± 0.4*	1.1 ± 0.3*	<.001
E/E′	7.9 ± 1.8	9.4 ± 2.6*	8.8 ± 2.1	9.3 ± 2.6*	.04

A = peak transmitral late diastolic velocity, E = peak transmitral early diastolic velocity, E′ = peak early diastolic mitral annular velocity, IVSD = interventricular septum diameter, LVEDD = left ventricular end-diastolic diameter, LVEDV = left ventricular end-diastolic volume, LVEF = left ventricular ejection fraction, LVESD = left ventricular end-systolic diameter, LVESV = Left ventricular end-systolic volume, LVFS = left ventricular short axis shortening rate, LVPWD = left ventricular posterior wall diameter.

*$P < .05$ versus control group.

†$P < .05$ versus mild OSAS group.

‡$P < .05$ versus moderate OSAS group.

Table 3

LVGLS values in different groups.

Variables	Control (n = 30)	Mild OSAS (n = 30)	Moderate OSAS (n = 30)	Severe OSAS (n = 36)	*P* value
LVGLS (%)	20.5 ± 1.1	19.8 ± 2	18.2 ± 1.4*,†	15.9 ± 1.4*,†,‡	<.001

LVGLS = left ventricular global longitudinal strain, OSAS = obstructive sleep apnea syndrome.

*$P < .05$ versus control group.

†$P < .05$ versus mild OSAS group.

‡$P < .05$ versus moderate OSAS group.

Table 4

The correlation analysis of left ventricular ultrasound parameters with AHI.

Variables	*r* value	*P* value
LVGLS	-0.732	<.001
LVEDD	0.188	.03
LVESD	0.044	.62
LVESV	0.063	.48
LVEDV	0.188	.03
IVSD	0.561	<.001
LVPWD	0.408	<.001
LVFS	0.148	.09
LVEF	0.138	.12
E/A	-0.411	<.001
E/E′	0.178	.04

A = peak transmitral late diastolic velocity, AHI = apnea–hypopnea index, E = peak transmitral early diastolic velocity, E′ = peak early diastolic mitral annular velocity, IVSD = interventricular septum diameter, LVEDD = left ventricular end-diastolic diameter, LVEDV = left ventricular end-diastolic volume, LVEF = left ventricular ejection fraction, LVESD = left ventricular end-systolic diameter, LVESV = Left ventricular end-systolic volume, LVFS = left ventricular fractional shortening, LVGLS = left ventricular global longitudinal strain, LVPWD = left ventricular posterior wall diameter.

echocardiographic parameters in detecting functional changes. Our results indicate that early cardiac dysfunction may already be present in subclinical OSAS patients, even when conventional echocardiographic parameters show no obvious abnormalities. This is consistent with previous studies.[21,22]

Our study suggests that subclinical OSAS patients may experience cardiac dysfunction even when conventional echocardiographic parameters do not show significant abnormalities. Previous studies have demonstrated that OSAS contributes to cardiovascular damage through multiple mechanisms. Recurrent hypoxia-reoxygenation cycles and hypercapnia, caused by repeated upper airway collapse, lead to excessive activation of the sympathetic nervous system and the renin–angiotensin–aldosterone system. This, in turn, results in endothelial dysfunction, vascular narrowing, structural changes in the heart and blood vessels, and hypertension.[23,24] Additionally, non-hemodynamic factors, such as increased oxidative stress, the secretion of inflammatory mediators, and insulin resistance, also play crucial roles in OSAS-related cardiovascular damage.[25,26] Furthermore, upper airway obstruction leads to compensatory breathing, which reduces intrathoracic pressure and increases pressure within the heart and large vessels. This pressure reduction enhances venous return to the heart.[27] The combined effects of these factors lead to increased cardiac preload and afterload, myocardial hypoxia, and microcirculatory disturbances. Ultimately, these changes result in myocardial remodeling and heart dysfunction. Our study found that LVGLS, as measured by the AutoStrain LV technique, is a sensitive method for detecting early cardiac dysfunction in subclinical OSAS patients.

Our study found that, in assessing LV diastolic function, the E/A ratio was lower in all OSAS subgroups compared to the control group, but this change did not correlate with OSAS severity. Additionally, the E/E′ ratio was higher in both the mild and severe OSAS groups compared to the control group, although no significant differences were observed between the OSAS subgroups. These results are inconsistent with some previous studies. For instance, some studies reported that the E/A ratio was only reduced in the mild OSAS group, with no significant abnormalities observed in the moderate and severe OSAS groups. In these studies, the E/E′ ratio was higher in the severe OSAS group compared to the healthy controls, as well as the mild and moderate OSAS groups, though no significant differences were found between the subgroups.[28] Other research indicated that the E/A ratio was significantly lower in the severe OSAS group compared to the mild and moderate groups, while the E/E′ ratio was elevated in the severe OSAS group.[29] Another study found that the E/A ratio was reduced in the severe OSAS group compared to controls, with

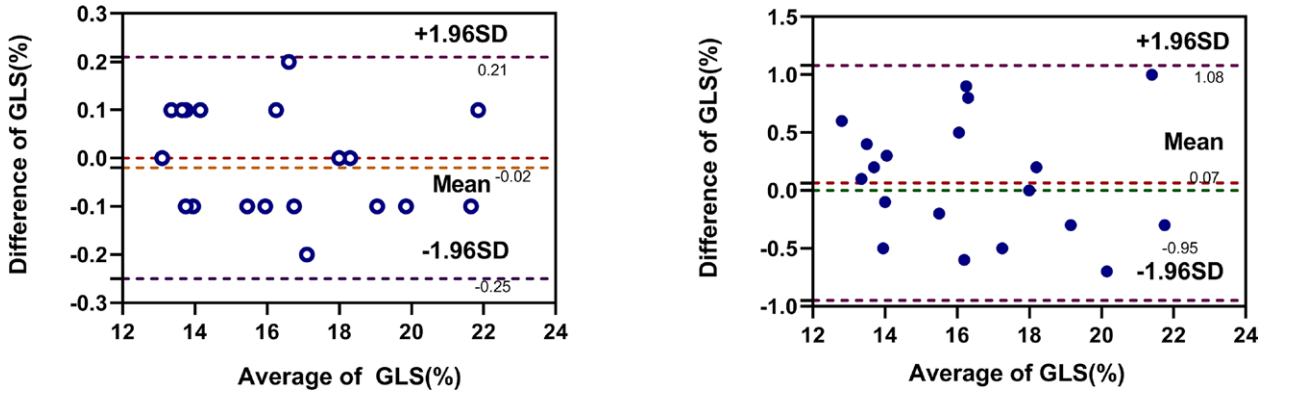

Figure 3. The Bland–Altman plots of the intraobserver (left column) and interobserver (right column) variability of LVGLS. LVGLS = left ventricular global longitudinal strain.

no significant abnormalities in the mild and moderate OSAS groups. Moreover, the E/E′ ratio was higher in all OSAS groups compared to controls, with the moderate and severe groups showing higher values than the mild group, although no significant differences were observed between the moderate and severe groups.[30] These findings suggest that conventional echocardiographic assessment of LV diastolic function in OSAS patients shows considerable variability, and no consensus has been reached. This inconsistency may be attributed to factors such as differences in study populations, comorbidities, and other confounding variables. Furthermore, the limitations of conventional echocardiographic techniques may also contribute to these discrepancies. For example, the E/A ratio measured by pulsed Doppler imaging can be influenced by factors like heart rate, respiration, age, and cardiac load, with heart rate increases potentially altering the E/A ratio. Additionally, while tissue Doppler imaging can detect early signs of cardiac dysfunction, it has its own limitations, such as dependence on sampling angles, susceptibility to noise, and frame rate issues.[13]

Currently, although many echocardiographic parameters are available to assess left heart function in OSAS patients, sensitive indicators correlated with the severity of OSAS remain unclear. In our study, we found that LVGLS had the strongest correlation with OSAS severity, suggesting that it may be a sensitive indicator of disease progression.

Although LVGLS has advantages in detecting subclinical myocardial injury,[14–16] its accurate assessment is challenging. Traditional STE techniques involve multiple manual steps, making the process complex, time-consuming, and highly dependent on the operator's experience. Consequently, the analysis is prone to human error and suffers from poor reproducibility and consistency. In contrast, AutoStrain technology is an emerging technology that combines two-dimensional STE with AI. It can automatically delineate the endocardial border and quantify myocardial strain values. This technology is accurate, fast, and reduces operator dependency and subjective bias. It also offers good reproducibility and consistency, making it a promising solution to overcome the limitations of traditional STE, with strong potential for clinical application. Kitano et al found that LVGLS measurements obtained using AutoStrain technology had excellent prognostic value in patients with subclinical aortic stenosis.[17] In another study, Yang et al demonstrated that automated LVGLS quantification was feasible, effective, and independently associated with mortality in asymptomatic chronic aortic regurgitation patients.[31] Similarly, Manzanares et al found that LVGLS, measured using the AutoStrain technique, is more effective than LVEF in detecting LV systolic dysfunction in children with acute lymphoblastic leukemia.[32]

5. Conclusion

The AutoStrain LV technique is a sensitive method for detecting subclinical LV dysfunction in OSAS patients, with LVGLS serving as a reliable indicator for monitoring.

6. Limitations

First, this was a single-center study with a small sample size, and larger multicenter studies are needed to further vali date our findings. Second, the AutoStrain LV technology, which combines AI with two-dimensional STE, may not fully capture the complexity of three-dimensional motion. Third, we did not include additional parameters for comparison. Furthermore, our study focused on subclinical OSAS patients without significant comorbidities, so the results may not be directly applicable to all OSAS patients.

Author contributions

Conceptualization: Yi Zhang, Shangyong Zhu.
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Investigation: Yi Zhang.
Methodology: Yi Zhang.
Project administration: Yi Zhang.
Resources: Yi Zhang, Shangyong Zhu.
Software: Yi Zhang.
Supervision: Shangyong Zhu.
Validation: Shangyong Zhu.
Writing – original draft: Yi Zhang.
Writing – review & editing: Yi Zhang, Shangyong Zhu.

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