BMC Cardiovascular Disorders

RESEARCH

Open Access

# Cardiac structural and functional changes in OSAHS patients with heart failure with preserved ejection fraction and atrial fibrillation

Huaqing Wei[1], Yan Luo[1], Cen Wei[2*], Huixian Liao[3] and Fengying Nong[4]

## Abstract

**Objective** To explore the cardiac structural and functional changes in obstructive sleep apnea-hypopnea syndrome (OSAHS) patients with heart failure with preserved ejection fraction (HFpEF) and atrial fibrillation (AF).

**Methods** This retrospective study included 336 OSAHS patients with HFpEF. They were divided into Groups A (without an AF history and no AF episodes during cardiac color ultrasound examination), B (an AF history but no AF episodes), and C (an AF history and AF episodes). They all received cardiac color ultrasound examinations. Cardiac structural and functional changes in ultrasonic cardiograms were compared between the three groups.

**Results** Compared with Groups A and B, Group C showed increased left atrial diameter (LAD), left atrial volume (LAV), right ventricular diameter at end-diastole (RV-D1), right ventricular diameter at end-systole (RV-D2), right ventricular outflow tract diameter (RVOT2), right atrial diameter at end-diastole (RA-D1), right atrial diameter at end-systole (RA-D2), and right atrial area (RAA) ($p < 0.05$). Compared with Group A, Group C showed decreased fractional shortening (FS), left ventricular ejection fraction (LVEF), deceleration time (DT), isovolumic relaxation time (IVRT), E/E' ratio, and peak filling velocity (FPV), as well as increased E and E' ($p < 0.01$). Compared with Group B, Group C showed decreased FS and increased E and FPV ($p < 0.01$).

**Conclusion** In OSAHS patients with HFpEF and AF, cardiac remodeling and AF incidence are increased with the severity of OSAHS. OSAHS patients with HFpEF combined with AF have a significantly higher abnormality rate in right heart structural indices rather than left heart, mainly in the right atrium.

**Keywords** Atrial fibrillation, Heart failure with preserved ejection fraction, Heart structure, Obstructive sleep apnea-hypopnea syndrome, Ultrasonic cardiogram

*Correspondence:
Cen Wei
weicengogo@126.com
[1]Department of Cardiology, Wuming Hospital of Guangxi Medical University, Nanning 530199, Guangxi Province, China
[2]ENT & HN Surgery Department, Wuming Hospital of Guangxi Medical University, No. 26 Yongning Road, Wuming District, Nanning 530199, Guangxi Province, China
[3]Department of Ultrasound Diagnosis, Wuming Hospital of Guangxi Medical University, Nanning 530199, Guangxi Province, China
[4]Department of Electrocardiogram Diagnosis, Wuming Hospital of Guangxi Medical University, Nanning 530199, Guangxi Province, China

## Introduction

Obstructive sleep apnea-hypopnea syndrome (OSAHS) is one of the most common sleep-disordered breathing disorders in which the upper airway repeatedly collapses and blocks during sleep, resulting in the disappearance of oronasal airflow and the existence of thoracoabdominal respiration [1]. Epidemiological data has shown that the incidence of OSAHS is increasing year by year [2]. It is estimated that 936 million people aged 30–69 worldwide suffered from OSAHS in 2019, of which there are about 425 million moderate to severe OSAHS cases [3]. OSAHS is mainly characterized by chronic intermittent hypoxia, sleep structure disorder, and repeated low ventilation and/or respiratory interruption during sleep, which can cause many pathophysiological changes in the body, especially in the cardiovascular system [4]. Long-term hypoxia in OSAHS patients can affect cardiac wall motion, cause right ventricular hypertrophy, and pulmonary hypertension, and even lead to heart failure [5].

OSAHS can cause severe arrhythmias and left ventricular hypertrophy [6], and it is an independent risk factor for the occurrence and development of atrial fibrillation (AF) [7]. A standard 12-lead ECG recording or a single-lead ECG tracing of > _30 s showing heart rhythm with no discernible repeating P waves and irregular RR intervals (when atrioventricular conduction is not impaired) is diagnostic of clinical AF [8, 9]. Accumulated evidence suggests that AF and heart failure (HF) have a mutual influence on each other and are causally related [10]. More than half of newly diagnosed HF patients have AF, and more than one-third of newly diagnosed AF patients have HF [11]. Heart failure with preserved ejection fraction (HFpEF) accounts for 40–50% of HF cases [12]. Patients with typical symptoms and signs of heart failure, left ventricular ejection fraction ≥ 50%, and the evidence of structural and/or functional cardiac abnormalities and/or raised natriuretic peptides (NPs) were diagnosed as HFpEF [13]. At present, there is still no clear diagnosis and treatment method to improve the clinical morbidity and mortality of HFpEF, which is related to the complexity of the pathogenesis of HFpEF and the irreversibility of heart failure itself [14, 15]. Some scholars have proposed that OSAHS is correlated with left ventricular mass and wall thickness, which can affect myocardial diastolic function to a certain extent [16]. However, the relationship between HFpEF characterized by myocardial diastolic dysfunction, and OSAHS is not clear. Therefore, we aimed to explore the cardiac structural and functional changes in OSAHS patients with HFpEF and AF.

## Subjects and methods

### Subjects

A total of 336 OSAHS patients with HFpEF who were treated at the Wuming Hospital Affiliated to Guangxi Medical University from May 2017 to October 2023 were included in this retrospective study. At the same time, 24-hour dynamic electrocardiogram monitoring or long-term dynamic electrocardiogram monitoring was used to determine whether AF was present. According to the guidelines for diagnosis and surgical treatment of OSAHS [17], patients were diagnosed with OSAHS by multi-channel sleep monitoring. HFpEF and AF were diagnosed according to the diagnostic criteria of 2021 European Society of Cardiology (ESC) [18] and the 2024 ESC AF guideline diagnostic criteria [19], respectively. A standard 12-lead ECG recording or a single-lead ECG tracing of > _30 s showing heart rhythm with no discernible repeating P waves and irregular RR intervals (when atrioventricular conduction is not impaired) is diagnostic of clinical AF. Patients with typical symptoms and signs of heart failure, left ventricular ejection fraction ≥ 50%, brain natriuretic peptide > 35 pg/ml or NT-pro natriuretic peptide > 125 pg/ml, and abnormal cardiac structure and function were diagnosed as HFpEF. Exclusion criteria: (1) central sleep apnea syndrome (CSAS); (2) long-term heavy alcohol consumption; (3) severe lung diseases, kidney diseases and brain diseases; (4) recent use of sleep aids; (5) congenital heart disease, valvular heart disease, myocardial or pericardial diseases, pacemaker implantation, sick sinus syndrome, or supraventricular tachycardia; (6) pulmonary embolism; (7) hyperthyroidism or hypothyroidism; (8) infections; (9) malignant tumors or leukemia.

### Grouping

All OSAHS patients were divided into mild group (153 cases), moderate group (114 cases), and severe group (69 cases) according to the severity of OSAHS. The severity of OSAHS was grouped according to the apnea-hypopnea index (AHI) value [17]: 5–15 as a mild group, 15–30 as a moderate group, and >30 as a severe group. Moreover, all OSAHS patients were divided into Group A (187 cases), Group B (56 cases), and Group C (93 cases) according to the presence of AF. Patients in Group A had no history of AF and no AF episodes during cardiac ultrasound examination, those in Group B had an AF history but no AF episodes, and those in Group C had an AF history and AF episodes.

### General information collection

All patients underwent detailed medical history inquiry and physical examination. Gender, age, smoking history, body mass index (BMI), blood pressure, heart rate (HR), New York Heart Association (NYHA) functional classification, and plasma B-type natriuretic peptide (BNP) were measured and recorded.

### Polysomnography (PSG)

The Embletta X20 multi-channel sleep analysis instrument (Natus Inc., Middleton, USA) was used to perform PSG. The patients were prohibited from taking food and drugs that affect sleep within 24 h before the examination, including central stimulants, sedative hypnotics alcohol and caffeine-containing food, etc. The nighttime sleep monitoring time was more than 7 h. PSG was automatically analyzed by a computer with manual assistance.

### Electrocardiography

12-lead dynamic electrocardiography (MDS300-4, MDS Software (Beijing) Co., Ltd., Beijing, China) was used for 24-h monitoring or long-term dynamic electrocardiography (CarePatch, ECG_P01, Hangzhou Proton Technology Co., Ltd., Hangzhou, China), and the electrocardiographic signals were automatically analyzed by a computer with its corresponding analysis software.

### Cardiac color ultrasound examination

According to the echocardiographic examination guidelines [20, 21], the German Siemens ACUSON SC2000 ultrasound diagnostic system was used for cardiac examination. All patients were measured by the same cardiac ultrasound technician in our hospital. The following indicators were measured as the average values of four consecutive cardiac cycles.

### Evaluating indicators

Left heart structural indicators included left ventricular end-diastolic interventricular septal thickness (IVSTd), posterior wall thickness (PWTH), end-diastolic diameter (LVEDD), relative wall thickness (RWT), left ventricular end-systolic diameter (LVESD), left ventricular end-diastolic and end-systolic volumes (LV-EDV, LV-ESV), left ventricular mass (LVM). Left atrial diameter (LAD), left atrial volume (LAV). Left ventricular shortening fraction (FS), and left ventricular ejection fraction (LVEF).

Right heart structural indicators: Diastolic right ventricle included basal diameter (RV-D1), mid-diameter (RV-D2), and basal to apical length (RV-D3). The diastolic and systolic free wall thickness of the right ventricle (RV-FWd, RV-FWs). Right ventricular outflow tract diameter included above the aortic valve (RVOT1), at the level of the pulmonary valve annulus (RVOT2). Right atrium: right atrial diameter at end-diastole (RA-D1), right atrial diameter at end-systole (RA-D2). Right atrial area (RA-A).

Left heart functional indicators: Early diastolic peak filling velocity (E peak) and E peak deceleration time (DT). Isovolumic relaxation time (IVRT) was measured in the apical five-chamber view. Tissue Doppler and its derived parameters: The maximum velocity of the mitral annulus lateral wall in early diastole (e') was measured in the apical four-chamber view, and the ratio (E/e') was calculated simultaneously. The peak filling velocity (FPV) was measured by the apical four-chamber view.

### Statistical analysis

Statistical Product and Service Solutions (SPSS) 26.0 statistical software was used for data analysis. Measurement data with non-normal distribution was represented by M(P25, P75), and the Kruskal-Wallis test was used for comparison between groups. Measurement data with normal distribution was represented by means ± standard deviation (SD), and one-way analysis of variance (ANOVA) was used for comparison between groups. Category data was expressed as percentages or composition ratios, and the chi-square test was used for comparison between groups. For pairwise comparison between the two groups, the Dunnett T3 test was used when the variance was unequal, and the Fisher's Least Significant Difference (LSD) test was used when the variance was equal. $p<0.05$ was considered statistically significant.

## Results

### General clinical data

In Group A, there were 94(50.3%) males and 93(49.7%) females, with an average age of 74.9 ± 9.2 years old. In Group B, there were 31(55.4%) males and 25(44.6%) females, with an average age of 71.3 ± 11.7 years old. In Group C, there were 53(57.0%) males and 40(43%) females, with an average age of 73.9 ± 10.4 years old. Compared with Group A, Group C showed increased body mass index (BMI), heart rate (HR), diastolic blood pressure (DBP), and brain natriuretic peptide (BNP), and decreased systolic blood pressure SBP ($p<0.05$). Group B showed notably increased BMI and BNP in comparison with Group A ($p<0.05$). Similarly, Group C showed significantly increased BMI and BNP and decreased SBP in comparison with Group B ($p<0.05$). There were no statistically significant differences in gender, age, smoking history, and NYHA classification among the three groups ($p>0.05$, Table 1).

### Comparison of left heart structure and AF incidence between the three OSAHS groups

All OSAHS patients were divided into mild group, moderate group, and severe group according to AHI value. The values of IVSTd, PWTH, LVEDD, RWT, LVM, LAD, LAV, and AF incidence all increased with the severity of OSAHS ($p<0.05$), and they all increased with the increased AHI. Compared with the mild and moderate groups, the severe group showed a decrease in FS and LVEF ($p<0.05$). There were no statistically significant differences in LV-EDV and LV-ESV among the three groups ($p>0.05$, Table 2).

**Table 1** Comparison of the demographic and clinic baseline characteristics between the three groups

| Items | Group A($n=187$) | Group B ($n=56$) | Group C ($n=93$) | $\chi^2$/F | $p$ |
|---|---|---|---|---|---|
| Male[n(%)] | 94(50.3) | 31(55.4) | 53(57.0) | 0.84 | 0.657 |
| Age(years) | 74.9 ± 9.2 | 71.3 ± 11.7 | 73.9 ± 10.4 | 2.81 | 0.617 |
| Smoke[n(%)] | 83(44.2) | 27(48.2) | 35(37.6) | 2.69 | 0.261 |
| BMI(kg/m$^2$) | 25.81 ± 6.09 | 28.43 ± 4.85$^{\#}$ | 31.93 ± 4.15$^{\#*}$ | 39.89 | < 0.001 |
| HR(time/min) | 78 ± 15 | 81 ± 17 | 83 ± 13$^{\#}$ | 3.72 | 0.025 |
| SBP(mmHg) | 131 ± 18 | 130 ± 15 | 124 ± 17$^{\#*}$ | 5.24 | 0.006 |
| DBP(mmHg) | 79 ± 12 | 82 ± 10 | 83 ± 11$^{\#}$ | 4.31 | 0.014 |
| BNP(pg/ml) | 674 ± 132 | 752 ± 145$^{\#}$ | 1053 ± 156$^{\#*}$ | 226.53 | < 0.001 |
| NYHA III-IV[n(%)] | 134(71.7) | 39(69.4) | 78(83.9) | 5.81 | 0.055 |
| Mild group [n(%)] | 118(63.1) | 24(42.9)$^{\#}$ | 11(11.8)$^{\#*}$ | 66.03 | < 0.001 |
| Moderate group [n(%)] | 51(27.3) | 21(37.5) | 42(45.2)$^{\#}$ | 9.25 | 0.010 |
| Severe group [n(%)] | 18(9.6) | 11(19.6)$^{\#}$ | 40(41.7)$^{\#*}$ | 42.45 | < 0.001 |

BMI, body mass index; HR, heart rate; NYHA, New York Heart Association; BNP, plasma B-type natriuretic peptide; SBP, systolic blood pressure; DBP, diastolic blood pressure. $^{\#}p<0.05$, compared with Group A; $^{*}p<0.05$, compared with Group B

**Table 2** Comparison of left heart structure and AF incidence between the three OSAHS groups

| Items | Mild group ($n=153$) | Moderate group ($n=114$) | Severe group ($n=69$) | $\chi^2$/F | $p$ |
|---|---|---|---|---|---|
| IVSTd (mm) | 8.9 ± 2.8 | 11.4 ± 3.1$^{\#}$ | 13.6 ± 4.7$^{\#*}$ | 61.51 | < 0.001 |
| PWTH(mm) | 9.4 ± 3.4 | 11.9 ± 3.1$^{\#}$ | 13.9 ± 2.9$^{\#*}$ | 47.84 | < 0.001 |
| LVEDD(mm) | 47.9 ± 5.3 | 54.6 ± 5.6$^{\#}$ | 56.1 ± 4.7$^{\#*}$ | 83.83 | < 0.001 |
| RWT(mm) | 0.39 ± 0.06 | 0.44 ± 0.06$^{\#}$ | 0.50 ± 0.07$^{\#*}$ | 76.86 | < 0.001 |
| LV-EDV(ml) | 74 ± 29 | 76 ± 24 | 79 ± 28 | 0.81 | 0.444 |
| LV-ESV(ml) | 32 ± 17 | 31 ± 14 | 35 ± 16 | 1.41 | 0.245 |
| LVM(g) | 201.4 ± 43.1 | 256.7 ± 37.9$^{\#}$ | 285.3 ± 40.7$^{\#*}$ | 119.22 | < 0.001 |
| LAD (mm) | 37.9 ± 6.4 | 45.7 ± 5.9$^{\#}$ | 48.7 ± 6.1$^{\#*}$ | 88.10 | < 0.001 |
| LAV(ml) | 83 ± 37 | 89 ± 41$^{\#}$ | 119 ± 40$^{\#*}$ | 20.91 | < 0.001 |
| FS(%) | 38 ± 18 | 38 ± 19 | 31 ± 16$^{\#*}$ | 4.16 | 0.016 |
| LVEF(%) | 69 ± 18 | 67 ± 15 | 62 ± 17$^{\#}$ | 4.12 | 0.017 |
| AF[n(%)] | 35(22.9) | 63(55.3) $^{\#}$ | 51(74.0)$^{\#*}$ | 58.52 | < 0.001 |
| Group A AF[n(%)] | 21(11.8) | 29(25.4)$^{\#}$ | 3(5.8)$^{\#*}$ | 15.36 | < 0.001 |
| Group B AF[n(%)] | 8(7.2) | 20(17.5)$^{\#}$ | 17(26.7)$^{\#}$ | 18.01 | < 0.001 |
| Group C AF[n(%)] | 6(3.9) | 14(12.3)$^{\#}$ | 31(44.9)$^{\#*}$ | 37.98 | < 0.001 |

IVSTd, left ventricular end-diastolic interventricular septal thickness; PWTH, posterior wall thickness; RWT, relative wall thickness; LVESD, left ventricular end-systolic diameter; LV-EDV, left ventricular end-diastolic volume; LV-ESV, left ventricular end-systolic volume; LVM, left ventricular mass; LAD, left atrial diameter; LAV, left atrial volume; FS, left ventricular shortening fraction; LVEF, left ventricular ejection fraction; AF, atrial fibrillation. $^{\#}p<0.05$, compared with mild group; $^{*}p<0.05$, compared with moderate group

### 3.3 Comparison of left heart structure between Groups A, B, and C

Compared with Groups A or B, Group C showed notably increased LAD and LAV ($p<0.01$). There were no statistically significant differences in IVSTd, PWTH, LVEDD, RWT, LVESD, LV-EDV, LV-EDVi, LV-ESV, and LVM among the three groups ($p>0.05$, Table 3).

### Comparison of right heart structure between Groups A, B, and C

Compared with Groups A and B, Group C showed increased RV-D1, RV-D2, RVOT2, RA-D1, RA-D2, and RAA ($p<0.05$). Compared with Group A, Group B showed an increase in RA-D2 and RVOT2 ($p<0.05$). There were no statistically significant differences in RV-D3, RV-FWd, RV-FWs, and RVOT1 among Groups A, B, and C ($p>0.05$, Table 4).

### Comparison of left heart function between Groups A, B, and C

Compared with Group A, Group C showed a decrease in FS, LVEF, DT, IVRT, E/E', and FPV, and an increase in E and E' ($p<0.01$). Compared with Group B, Group C showed a decrease in FS and an increase in E and FPV ($p<0.01$, Table 3).

## Discussion

There have been few reports on the correlation between cardiac structural and functional characteristics and the severity of disease in OSAHS patients. OSAHS can induce and worsen diseases such as HF and arrhythmias [6], and OSAHS is also an independent risk factor for AF [7, 8]. Currently, the changes in cardiac structure and function in these patients and the mechanisms of AF in cardiac structural changes are not clear. In this study, we

**Table 3** Comparison of left heart structure between Groups A, B and C

| Items | Group A($n=187$) | Group B($n=56$) | Group C($n=93$) | $\chi^2$/F | *p* |
|---|---|---|---|---|---|
| IVSTd(mm) | 10.8 ± 1.3 | 10.5 ± 1.2 | 10.5 ± 1.4 | 2.17 | 0.116 |
| PWTH(mm) | 11.2 ± 1.2 | 11.1 ± 1.5 | 11.0 ± 1.3 | 0.77 | 0.463 |
| LVEDD(mm) | 48.7 ± 6.5 | 49.3 ± 7.2 | 48.6 ± 6.0 | 0.23 | 0.795 |
| RWT(mm) | 0.46 ± 0.02 | 0.45 ± 0.03 | 0.45 ± 0.07 | 2.40 | 0.092 |
| LVESD(mm) | 51.2 ± 4.3 | 51.8 ± 4.8 | 52.4 ± 5.1 | 2.14 | 0.119 |
| LV-EDV(ml) | 75 ± 26 | 76 ± 30 | 78 ± 29 | 0.37 | 0.692 |
| LV-EDVi(ml/m$^2$) | 46.5 ± 15.7 | 43.9 ± 16.9 | 42.7 ± 18.3 | 1.77 | 0.172 |
| LV-ESV(ml) | 30 ± 18 | 33 ± 15 | 34 ± 17 | 1.89 | 0.153 |
| LVM(g) | 204.3 ± 37.3 | 210.4 ± 45.1 | 212.2 ± 43.8 | 1.35 | 0.260 |
| LAD(mm) | 38.7 ± 5.7 | 40.1 ± 6.4 | 52.5 ± 6.0$^{\#*}$ | 176.45 | < 0.001 |
| LAV(ml) | 87 ± 34 | 92 ± 42 | 105 ± 39$^{\#*}$ | 7.43 | 0.001 |
| FS% | 38 ± 14 | 37 ± 18 | 31 ± 15$^{\#*}$ | 6.94 | 0.001 |
| LVEF% | 69 ± 16 | 65 ± 13 | 63 ± 15$^{\#}$ | 5.20 | 0.006 |
| E(cm/s) | 76 ± 23 | 89 ± 21$^{\#}$ | 97 ± 27$^{\#*}$ | 25.53 | < 0.001 |
| DT(ms) | 247 ± 34 | 234 ± 33$^{\#}$ | 231 ± 41$^{\#}$ | 7.23 | 0.001 |
| IVRT(ms) | 84 ± 22 | 81 ± 27 | 76 ± 23$^{\#}$ | 3.71 | 0.026 |
| e'(cm/s) | 5.4 ± 1.1 | 8.1 ± 1.3$^{\#}$ | 8.3 ± 1.2$^{\#}$ | 245.09 | < 0.001 |
| E/e'(cm/s) | 14.3 ± 3.5 | 13.7 ± 3.1 | 10.9 ± 3.9$^{\#}$ | 28.94 | < 0.001 |
| FPV(cm/s)) | 42 ± 24 | 47 ± 23 | 53 ± 27$^{\#*}$ | 5.96 | 0.003 |

IVSTd, left ventricular end-diastolic interventricular septal thickness; PWTH, posterior wall thickness; RWT, relative wall thickness; LVESD, left ventricular end-systolic diameter; LV-EDV, left ventricular end-diastolic volume; LV-ESV, left ventricular end-systolic volume; LVM, left ventricular mass; LAD, left atrial diameter; LAV, left atrial volume; FS, left ventricular shortening fraction; LVEF, left ventricular ejection fraction; E peak, Early diastolic peak filling velocity; DT, E peak deceleration time; IVRT, Isovolumic relaxation time; e', the maximum velocity of the mitral annulus lateral wall in early diastole; E/e', the ratio; FPV, peak filling velocity. $^{\#}p<0.05$, compared with Group A; $^{*}p<0.05$, compared with Group B

**Table 4** Comparison of right heart structure between Groups A, B and C

| Items | Group A($n=187$) | Group B($n=56$) | Group C($n=93$) | $\chi^2$/F | *p* |
|---|---|---|---|---|---|
| RV-D1 (mm) | 34.2 ± 5.7 | 34.9 ± 4.8 | 38.1 ± 6.3$^{\#*}$ | 14.60 | < 0.001 |
| RV-D2(mm) | 29.2 ± 5.9 | 29.7 ± 6.1 | 32.6 ± 6.7$^{\#*}$ | 9.69 | < 0.001 |
| RV-D3(mm) | 61.4 ± 8.3 | 59.1 ± 8.9 | 59.3 ± 9.1 | 2.64 | 0.073 |
| RV-FWd(mm) | 4.3 ± 0.5 | 4.3 ± 0.4 | 4.4 ± 0.5 | 1.43 | 0.241 |
| RV-FWs (mm) | 6.2 ± 1.1 | 6.3 ± 1.3 | 6.4 ± 1.3 | 0.89 | 0.411 |
| RVOT1(mm) | 27.1 ± 3.7 | 27.4 ± 3.6 | 27.3 ± 3.4 | 0.19 | 0.824 |
| RVOT2(mm) | 23.2 ± 3.2 | 25.5 ± 3.0$^{\#}$ | 30.3 ± 3.4$^{\#*}$ | 150.54 | < 0.001 |
| RA-D1(mm) | 39.5 ± 5.9 | 41.3 ± 6.1 | 46.9 ± 7.1$^{\#*}$ | 43.29 | < 0.001 |
| RA-D2(mm) | 50.8 ± 6.1 | 55.4 ± 6.3$^{\#}$ | 62.7 ± 6.7$^{\#*}$ | 110.91 | < 0.001 |
| RA-A(cm$^2$) | 17.3 ± 5.9 | 18.4 ± 6.2 | 26.7 ± 7.1$^{\#*}$ | 71.49 | < 0.001 |

RV-D1, diastolic right ventricle included basal diameter; RV-D2, diastolic right ventricle included mid-diameter; RV-D3, diastolic right ventricle basal to apical length; RV-FW, diastolic and systolic free wall thickness of the right ventricle; RVOT1, right ventricular outflow tract diameter above the aortic valve; RVOT2, right ventricular outflow tract diameter at the level of the pulmonary valve annulus; RA-D1, right atrium: short-axis diameter; RA-D2, right atrium: short-axis diameter: long-axis diameter; RA-A, right atrial area. $^{\#}p<0.05$, compared with Group A; $^{*}p<0.05$, compared with Group B

found that in OSAHS patients with HFpEF complicated with AF, there is a close correlation between cardiac structural and functional characteristics, the severity of OSAHS, and the presence of AF.

In our study, except for LV-EDV and LV-ESV, the left atrial and left ventricular structural indices in OSAHS patients were significantly increased with the severity of OSAHS. At the same time, AF incidence was notably increased with the severity of OSAHS. The reason for this may be that OSAHS can worsen cardiac remodeling through hemodynamic changes, oxidative stress, and inflammatory reactions, including structural, electrical, and metabolic remodeling of the atria, which play an important role in the occurrence and development of AF [22–24].

We found that in OSAHS patients with AF, compared with the abnormal rate of left heart structure indices of 18.2% (2/11), the abnormal rate of right heart structure indices was 60% (6/10), and this manifestation was mainly in the right atrium. It is speculated that OSAHS and AF cause cardiac remodeling more obvious in the right heart, which is superimposed on HFpEF patients. Melenovsky et al. also found the same results in HFpEF patients, in whom the right ventricle and right atrium showed more obvious structural changes compared to

the left heart, with the right atrium showing more significant changes [25].

There is a relationship between right heart structural remodeling and AF. About 30% of HFpEF patients have right ventricular dilation, and 34–50% have right ventricular hypertrophy [25]. AF is closely related to the decline in right ventricular and right atrial function and is independent of pulmonary pressure [26]. It is believed that right ventricular dilatation may not be able to withstand the long-term increased afterload of pulmonary artery pressure. To adapt to the change of afterload, the right ventricular wall is thickened, resulting in limited dilatation. In this study, based on the increase in intrathoracic negative pressure caused by OSAHS, compared with OSAHS patients without AF, those with AF had significant changes in right heart structure indices, and the right heart cavity was significantly enlarged. The interaction between genetic susceptibility, abnormal atrial tissue matrix, and ectopic electrical activity leads to the occurrence of atrial fibrillation [27]. Factors such as atrial enlargement and myocardial fibrosis contribute to the development of atrial remodeling [28]. Similarly, our results showed that right heart structural changes promoted the occurrence of AF with poorer cardiac functions. At the same time, the occurrence of AF can lead to irregular atrial motion, which further exacerbates atrial remodeling. When AF occurs continuously or frequently, it leads to more prominent atrial remodeling, forming a vicious cycle between atrial remodeling and AF.

The large blood vessels in the thoracic cavity and the thin-walled atrium, especially the large vein, are easily affected by the negative pressure in the thoracic cavity formed by OSAHS and its pressure fluctuation, resulting in a significant increase in the amount of right heart blood reflux and long-term overload [29]. Hypercapnia and intermittent hypoxia in OSAHS patients lead to pulmonary vascular endothelial injury and vascular structural remodeling, increased pulmonary artery stiffness, and pulse pressure, finally resulting in increased right ventricular afterload [30]. In patients with HFpEF, impaired left ventricular diastolic function and increased filling pressure lead to increased pressure transmitted to the pulmonary artery through the left atrium and pulmonary vein, resulting in increased pulmonary artery pressure and increased right ventricular afterload [31]. It has been reported that in AF patients, the use of $H_2$FPEF and HFA-PEFF scores did not predict elevated mean left atrial pressure [32]. This study found that there is right heart structural remodeling, especially atrial remodeling, with the progression of OSAHS. Heart structural remodeling mainly includes atrial enlargement or hypertrophy, tissue fibrosis, and changes in atrial myocardial ultrastructure, which are one of the main reasons for AF maintenance [33, 34]. Based on the mechanisms of AF formation (such as structural remodeling, electrical remodeling, and inflammation), we speculate that with the progression of OSAHS, AF may not be continuously correlated with the increase in pulmonary artery pressure caused by worsening left ventricular diastolic dysfunction. This indicates that severe HFpEF does not necessarily lead to the occurrence of AF. In OSAHS patients with HFpEF and AF, the right heart structural changes are not closely related to the progression of HFpEF.

In this study, in groups B and C, diastolic dysfunction was not significant, but significant cardiac structural changes were observed. The reasons for this may be that OSAHS can cause or even exacerbate cardiac remodeling, and it may also be related to the cognition of physicians and patients regarding AF. AF occurring in patients with OSAHS and HFpEF is diagnosed and treated early because diastolic dysfunction is not significant. On the contrary, in OSAHS patients with HFpEF without AF, HFpEF symptoms often appear in the late stage, because diastolic dysfunction has already occurred. Therefore, in clinical practice, significant cardiac structural changes often occur in OSAHS patients with HFpEF and AF, while diastolic dysfunction has not yet occurred.

In this study, we emphasized that in the diagnosis and treatment of HFpEF patients with OSAHS, especially in the case of AF, more attention should be paid to the comprehensive assessment of cardiac structure and function, including the left and right hearts. Early identification and monitoring of these changes is of great significance for timely adjustment of treatment strategies and prevention of further deterioration of the disease. In addition, attention to the structure and function of the right heart may lead to the exploration of new therapeutic targets and interventions. Future research can further explore the specific mechanism and role of the right heart in such complex disease conditions, and develop more accurate methods and techniques for evaluating right heart function. At the same time, individualized treatment strategies for these patients can be optimized, including how to better manage OSAHS, control atrial fibrillation, and improve cardiac remodeling.

There are also some limitations in this study. First, this is a single center study with small sample size. Second, this study lacks patient's medical history of diabetes mellitus, which may introduce certain biases to the results. It is necessary to expand the sample size and collect data in this regard for further analysis. Third, we did not explore the effect of pulmonary artery pressure in the study, and it did not explain the changes in pulmonary artery pressure in OSAHS patients with concomitant HFpEF and AF. Whether pulmonary artery pressure would affect right heart remodeling may require more prospective studies.

## Conclusions

In OSAHS patients with HFpEF and AF, cardiac remodeling and AF incidence are increased with the severity of OSAHS. OSAHS patients with HFpEF who are combined with AF have a significantly higher abnormality rate in right heart structural indices rather than left heart, mainly in the right atrium.

**Acknowledgements**
None.

**Author contributions**
Huaqing Wei performed the research and wrote the paper; Yan Luo designed the research; Cen Wei and Huixian Liao contributed to the analysis; Fengying Nong organized the materials; Cen Wei guided and supervised the research. All authors reviewed and approved the final manuscript.

**Funding**
None.

**Data availability**
Clinical data used in this study can be obtained from the corresponding author.

## Declarations

**Ethics approval and consent to participate**
The study was approved by the ethics committee of Wuming Hospital of Guangxi Medical University [Approval No. WM-2017(235)], and informed consent was obtained from all patients.

**Consent for publication**
Not applicable.

**Competing interests**
The authors declare no competing interests.

Received: 12 March 2024 / Accepted: 20 September 2024
Published online: 16 October 2024

**References**

1. Li Y, Wang Y. Obstructive sleep apnea-hypopnea syndrome as a novel potential risk for aging. Aging Dis. 2021;12(2):586–96.
2. Zeng X, Ma D, Wu K, et al. Development and validation of a clinical model to predict hypertension in consecutive patients with obstructive sleep apnea-hypopnea syndrome: a hospital-based study and nomogram analysis. Am J Transl Res. 2022;14(2):819–30.
3. Benjafield AV, Ayas NT, Eastwood PR, et al. Estimation of the global prevalence and burden of obstructive sleep apnoea: a literature-based analysis. Lancet Respir Med. 2019;7(8):687–98.
4. Yao X, Li N, Heizhati M, et al. Obstructive sleep apnea remains a risk factor for major adverse cardiovascular and cerebrovascular events even in hypertensive patients under treatment: the Urumqi Research on Sleep Apnea and Hypertension (UROSAH) data. Cardiovasc Diagn Ther. 2023;13(6):968–78.
5. Shin JH, Song MJ, Kim JH. Acute Effect of positive Airway pressure on Heart Rate Variability in Obstructive Sleep Apnea. J Clin Med. 2023;12(24):7606.
6. Diamond JA, Ismail H. Obstructive Sleep Apnea and Cardiovascular Disease. Clin Geriatr Med. 2021;37(3):445–56.
7. Li F, He CJ, Ding CH, Wang RX, Li H. Continuous positive airway pressure therapy might be an effective strategy on reduction of atrial fibrillation recurrence after ablation in patients with obstructive sleep apnea: insights from the pooled studies. Front Neurol. 2023;14:1269945.
8. Hindricks G, Potpara T, Dagres N, et al. 2020 ESC guidelines for the diagnosis and management of atrial fibrillation developed in collaboration with the European Association for Cardio-Thoracic Surgery (EACTS): the Task Force for the diagnosis and management of atrial fibrillation of the European Society of Cardiology (ESC) developed with the special contribution of the European Heart Rhythm Association (EHRA) of the ESC [published correction appears in. Eur Heart J. 2021;42(5):507.
9. Joglar JA, Chung MK, Armbruster AL et al. 2023 ACC/AHA/ACCP/HRS Guideline for the diagnosis and management of Atrial Fibrillation: a report of the American College of Cardiology/American Heart Association Joint Committee on Clinical Practice Guidelines [published correction appears in circulation. 2024;149(1):e167.
10. Bergau L, Bengel P, Sciacca V, Fink T, Sohns C, Sommer P. Atrial fibrillation and heart failure. J Clin Med. 2022;11(9):2510.
11. Santhanakrishnan R, Wang N, Larson MG, et al. Atrial Fibrillation Begets Heart failure and Vice Versa: temporal associations and differences in preserved Versus reduced ejection fraction. Circulation. 2016;133(5):484–92.
12. Tschöpe C, Birner C, Böhm M, et al. Heart failure with preserved ejection fraction: current management and future strategies: Expert opinion on the behalf of the Nucleus of the Heart Failure Working Group of the German Society of Cardiology (DKG). Clin Res Cardiol. 2018;107(1):1–19.
13. McDonagh TA, Metra M, Adamo M, et al. 2021 ESC guidelines for the diagnosis and treatment of acute and chronic heart failure [published correction appears in. Eur Heart J. 2021;42(48):4901.
14. Smart CD, Madhur MS. The immunology of heart failure with preserved ejection fraction. Clin Sci (Lond). 2023;137(16):1225–47.
15. Li X, Sun M, Wang Z, Sun S, Wang Y. Recent advances in mechanistic studies of heart failure with preserved ejection fraction and its comorbidities-role of microRNAs. Eur J Clin Invest Published Online Dec 9, 2023.
16. Baguet JP, Barone-Rochette G, Tamisier R, Levy P, Pépin JL. Mechanisms of cardiac dysfunction in obstructive sleep apnea. Nat Rev Cardiol. 2012;9(12):679–88.
17. Editorial Board of Chinese Journal of Otorhinolaryngology-Head and Neck Surgery, Throat Group of Otorhinolaryngology-Head and Neck Surgery Branch of Chinese Medical Association. Guidelines for diagnosis and Surgical Treatment of Obstructive Sleep Apnea Hypopnea Syndrome. Chin J Otorhinolaryngol Head Neck Surg. 2009;44(2):95–6.
18. McDonagh TA, Metra M, Adamo M, et al. 2021 ESC guidelines for the diagnosis and treatment of acute and chronic heart failure. Eur Heart J. 2021;42(48):4901.
19. Van Gelder IC, Rienstra M, Bunting KV et al. 2024 ESC guidelines for the management of atrial fibrillation developed in collaboration with the European Association for Cardio-Thoracic Surgery (EACTS). Eur Heart J. 2024; ehae176.
20. Ultrasound Physicians Branch of Chinese Medical Association. Guidelines for echocardiographic examination. Beijing: People's Military Medical Publishing House; 2016. p. 01.
21. Echocardiography Group of Chinese Society of Ultrasonic Medicine. Chinese adult echocardiography measurement guidelines. Chin J Ultrasonography. 2016;25(008):645–66.
22. Du Z, Sun H, Du Y, et al. Comprehensive Metabolomics and Machine Learning identify Profound oxidative stress and Inflammation Signatures in hypertensive patients with obstructive sleep apnea. Antioxid (Basel). 2022;11(10):1946.
23. Lu D, Wang K, Jiang W, Zhang H, Zhang H. Effect of renal denervation on cardiac remodeling and function in rats with chronic intermittent hypoxia. Clin Exp Pharmacol Physiol. 2023;50(9):719–27.
24. Zhang B, Lu S, Guo H, Xu J, Xiao Z, Tang J. Relationship between ODI and sleep structure of obstructive sleep apnea and cardiac remodeling. Sleep Breath Published Online July 15, 2023.
25. Melenovsky V, Hwang SJ, Lin G, et al. Right heart dysfunction in heart failure with preserved ejection fraction. Eur Heart J. 2014;35(48):3452–62.
26. Gorter TM, van Melle JP, Rienstra M, et al. Right heart dysfunction in heart failure with preserved ejection fraction: the impact of Atrial Fibrillation. J Card Fail. 2018;24(3):177–85.
27. Lau DH, Linz D, Schotten U, et al. Pathophysiology of Paroxysmal and Persistent Atrial Fibrillation: rotors, Foci and Fibrosis. Heart Lung Circulation. 2017;26(9):887–93.
28. Wijesurendra RS, Casadei B. Mechanisms of atrial fibrillation[J]. Heart. 2019;105(24):1860–7.
29. Lowery MM, Hill NS, Wang L, et al. Sleep-related hypoxia, right ventricular dysfunction, and survival in patients with Group 1 Pulmonary arterial hypertension. J Am Coll Cardiol. 2023;82(21):1989–2005.
30. Karacaglar E, Bal U, Eroglu S, et al. Pulmonary artery distensibility is worsened in Obstructive Sleep Apnea Syndrome. Acta Cardiol Sinica. 2019;35(5):501–7.
31. Claeys M, Petit T, Bogaert J, et al. Dynamic aspects of ventricular interaction during exercise in HFpEF and in pre-capillary pulmonary hypertension. ESC Heart Fail. 2023;10(1):650–60.

32. Bonelli A, Degiovanni A, Beretta D, et al. H2FPEF and HFA-PEFF scores performance and the additional value of cardiac structure and function in patients with atrial fibrillation. Int J Cardiol. 2024;413:132385.
33. Bizhanov KA, Abzaliyev KB, Baimbetov AK, Sarsenbayeva AB, Lyan E. Atrial fibrillation: Epidemiology, pathophysiology, and clinical complications (literature review). J Cardiovasc Electrophysiol. 2023;34(1):153–65.
34. Arabia G, Bellicini MG, Cersosimo A, et al. Ion channel dysfunction and fibrosis in atrial fibrillation: two sides of the same coin. Pacing Clin Electrophysiol. 2024;47(3):417–28.

## Publisher's note