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Obstructive sleep apnea: Is it a biomarker of metabolic health in obesity

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Abstract

Context: The prevalence of obstructive sleep apnea (OSA) increases with obesity, and OSA has been linked to increased cardiovascular risk via hypoxemia and sleep disruption.

Objective and Main Outcome Measure(s): We hypothesized that if OSA contributes to cardio-metabolic risk, then 1) obese individuals with OSA will have more cardio-metabolic disease, and 2) patients with OSA who are non-adherent to CPAP treatment will have a greater incidence of cardio-metabolic abnormalities.

Design, setting and patients: We prospectively recruited obese patients (n = 83; BMI 49 ± 9 kg/m^2). All patients had polysomnography and were stratified by 1) the absence/presence of OSA, and 2) metabolic health. Detailed CPAP reports were analyzed for compliance and OSA severity in 38 subjects.

Results: OSA by polysomnography was present in 69% of patients. While 79% of patients with OSA and 54% without OSA were categorized as MAO ($\chi^2 = 5.47$, $p < 0.02$), when adjusted for age, gender and BMI this difference was not significant ($p = 0.36$). Insulin levels were higher in the OSA group, but when adjusted there was no significant difference ($p = 0.350$). In patients on CPAP therapy, there was a negative associative trend between OSA control (apnea-hypopnea index) and beta-cell function (HOMA-β) ($r = -0.406$, $p = 0.076$), but no association between CPAP compliance and AHI with age, BMI, glucose, insulin, adiponectin, or insulin resistance.

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Author contributions

NMB designed the study, performed analysis, and wrote the manuscript; **BN and SN** recruited participants and reviewed/edited the manuscript; **DB** designed the study, performed analysis, and reviewed/edited the manuscript.

Disclosure statement

The authors have nothing to disclose.

Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.obmed.2017.04.002

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Conclusions: OSA is not independently associated with overall cardio-metabolic health and insulin resistance in obese patients, even when accounting for treatment compliance. The strongest predictors of the obese metabolic healthy phenotype in OSA patients are age, gender and BMI.

Keywords

Sleep apnea; Obesity; Metabolism

1. Introduction

Obesity is associated with numerous metabolic complications including Type 2 diabetes mellitus (T2DM), hypertension (HTN), dyslipidemia, non-alcoholic fatty liver disease (NAFLD) and steatohepatitis (NASH), cardiovascular disease (CVD) and several forms of cancer (Flegal et al., 2012). However, the presence of these obesity-related metabolic abnormalities varies among obese individuals (Bonora et al., 1998; Ferrannini et al., 1997). The phenotype of a metabolically healthy obese (MHO) individual was initially described in 1980 and includes a subset of obese patients (as defined by body mass index [BMI]) who do not manifest the typical metabolic abnormalities associated with obesity (Karelis et al., 2004). Although results are conflicting, highly dependent on the studied patient population, and differ based on the diagnostic criteria for metabolic health used (Phillips, 2013), these individuals tend to have a preserved level of insulin sensitivity, absence of HTN, and a more favorable lipid, inflammatory, and immunologic profile compared to metabolically abnormal obese (MAO) patients (Karelis et al., 2004; Aguilar-Salinas et al., 2008; Lynch et al., 2009; Stefan et al., 2008). This seeming paradox underscores that excess body weight is not the sole determinant of obesity-related complications and allows for novel pathogenic investigation.

The postulated mechanism(s) underlying the differential risk in these obese individuals is not well known and the physiologic and molecular basis for ‘healthy’ obesity remains relatively undiscovered. In addition, a recent meta-analysis demonstrated that although MHO patients have a comparable metabolic profile to normal weight individuals, their risk of adverse, long-term CV and mortality outcomes remains higher, calling into question the clinical importance of the healthy obese categorization (Kramer et al., 2013). Despite these knowledge gaps, a number of studies have recently attempted to elucidate the processes that lead to the MHO profile, including characterization of lifestyle factors and physical activity level, adipocyte size, amount and location of ectopic fat, inflammatory mediators, immune cells, and differences in gene expression (Badoud et al., 2015).

The prevalence of obstructive sleep apnea (OSA) increases with escalating BMI and has also been linked to various cardiometabolic abnormalities (Luciano et al., 2013). OSA may exert negative effects on the CV system through multiple mechanisms including hypoxemia, sleep disruption, activation of the sympathetic nervous system, and inflammatory activation (Zamarron et al., 2013). In spite of this proposed connection, the contribution of these OSA-related deleterious effects in determining the MHO vs. MAO phenotype is currently unknown. Furthermore, the prevalence of OSA in these two obese subsets is not well established.

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In this study, we hypothesized that if OSA independently contributes to metabolic disease and heightens CV risk, then obese individuals with OSA will have a greater cardio-metabolic disease burden compared to BMI-matched patients without OSA. We further hypothesized that subjects with OSA who are non-compliant and poorly controlled with continuous positive airway pressure (CPAP) will also have a greater incidence of cardio-metabolic disease, be more likely to be categorized as MAO, and have heightened insulin resistance and impaired beta (β)-cell function compared to well-managed CPAP compliant patients.

2. Materials and methods

2.1. Selection and description of participants

We prospectively recruited obese patients scheduled to undergo bariatric surgery at The Ohio State University Center for Minimally Invasive Surgery. All patients had formal testing for OSA with polysomnography and analysis was performed prior to surgical intervention. A diagnosis of OSA was defined by either the presence of 1) greater than 4 predominantly obstructive respiratory events per hour of sleep by polysomnography (obstructive and mixed apneas, hypopneas, or respiratory effort related arousals) with one or more symptoms or OSA-related comorbidities, or 2) greater than 14 predominantly obstructive respiratory events per hour of sleep in the absence of associated symptoms or comorbidities (American Academy of Sleep Medicine, 2014). Subjects were further stratified into subgroups by 1) the absence (negative polysomnography) or presence (positive polysomnography or use of CPAP) of OSA, and 2) the absence or presence of 4 cardio-metabolic abnormalities: hypertension (blood pressure ≥ 130/80 mmHg and/or treatment with antihypertensive medications), T2DM/prediabetes (glycated hemoglobin ≥5.7% and/or treatment with diabetes medications), dyslipidemia (triglycerides ≥ 150 mg/dL, LDL ≥ 130, HDL < 50 for women and <40 for men, and/or treatment with lipid lowering medications), and fatty liver disease. Metabolically healthy obese (MHO) participants were defined as having ≤ 1 of these cardiometabolic disorders.

2.2. Experimental procedures

Individual CPAP compliance reports were available and reviewed for a subset of 38 subjects with OSA. A standard compliance report provides detailed information about device settings, pressure and leak values, apnea and hypopnea events per hour, and usage data including the number of days a patient uses the device for greater than or less than 4 h, average daily use, total hours used, and median daily usage. We defined CPAP compliant patients as usage >4 h per night on 70% of nights.

Blood samples were collected and analyzed for glucose, insulin, and adiponectin levels by ELISA (Millipore, Billerica, MA). The homeostasis model assessment for estimated insulin resistance (HOMA-IR) and beta-cell function (HOMA-β) were calculated as follow:

$$\text{HOMA-IR} = \text{Glucose (mg/dL)} \times \text{Insulin}/405$$

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$$\text{HOMA-}\beta = 360 \times \text{Insulin/Glucose (mg/dL)} - 63\%$$

2.3. Statistical analysis

Data were examined for normality according to the Shapiro-Wilks criteria. Continuous variables were compared by subject group through one-way ANOVA for normally distributed variables and Mann-Whitney *U* test for non-normally distributed variables. Ordinal variables were analyzed by group via the Chi-Square test. Further analysis was performed using analysis of covariance (ANCOVA), with BMI, age and gender as independent covariate or confounding variables. For association analyses, Pearson's correlations were used for normally distributed data and Spearman's correlations for non-normally distributed data. Multivariate linear regression with age, gender and BMI as independent variables was performed for significant correlations. A p-value of ≤0.05 was considered statistically significant. All data are presented as means ± standard deviation.

2.4. Study approval

This study was approved by the Human Research Protection Office at The Ohio State University School of Medicine in Columbus, OH. All study subjects provided written informed consent before screening and participation in the study.

3. Results

3.1. Prevalence of OSA and cardio-metabolic abnormalities

A total of 83 patients (BMI 49 ± 9 kg/m2) were included in the overall analyses: Of this total cohort, fifty-seven (~69%) patients had OSA and twenty-six (~31%) patients did not have OSA. Patients with OSA were older, heavier, and more likely to be male, but there were no significant racial differences between the two cohorts (Table 1). While a greater proportion of patients with OSA (79%) compared to those without OSA (54%) had ≥ 2 cardio-metabolic abnormalities ($\chi^2 = 5.47$, $p < 0.02$) (Fig. 1), when adjusted for age, gender and BMI by covariate analysis this difference was nonsignificant ($p = 0.36$). Among all cardio-metabolic complications, HTN was more common in patients with OSA ($\chi^2 = 6.70$; p-value = 0.01), but when adjusted for age, gender and BMI this difference was also nonsignificant ($p = 0.29$). There were no significant differences in the presence of T2DM, dyslipidemia, fatty liver disease, or abnormal liver function tests (LFTs) in those with vs. without OSA.

3.2. Relationship between OSA and glucoregulatory determinants

Patients with OSA had significantly higher fasting glucose, insulin, and degree of insulin resistance (HOMA-IR) compared to patients without OSA (Table 2); however, these differences were due to disparities in age, gender and BMI between the two groups and were not independent of OSA status. There were also no differences in beta-cell function (HOMA-B) or plasma adiponectin between those with and without OSA.

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3.3. OSA and metabolically healthy (MHO) and abnormal (MAO) obese phenotypes

Overall 59 (71%) patients met the definition of MAO, 24 (21%) were categorized as MHO. There were no significant differences in gender or race between MAO and MHO patients, but MAO patients were on average older and heavier (with a graded increase with more severe obesity class). MAO patients were more likely to have OSA (54.2% vs. 14.5%, $p = 0.019$) (Table 3), significantly higher HOMA-B ($p = 0.017$) levels, and exhibit trends for higher fasting glucose, insulin and HOMA-IR levels. However, when accounting for age, gender and BMI, there were no differences between MAO and MHO patients in fasting glucose, insulin or HOMA-IR levels but a trend for higher HOMA-B ($p = 0.086$). Plasma adiponectin levels were not different based on metabolic health ($p = 0.852$) (Table 3). Patients with OSA classified as MAO were older and had higher BMI compared with those without OSA who were categorized as MHO and had higher fasting insulin and HOMA-B and a trend for higher insulin resistance (HOMA-IR levels) (Supplementary Table 1). When adjusted for age, BMI, and gender, however, there were no significant differences.

3.4. Relationship between treatment compliance and cardiometabolic abnormalities

In a subset of patients on CPAP with detailed CPAP compliance reports available: there were no differences in the prevalence of prediabetes/T2DM ($\chi^2 = 2.70$, $p = 0.259$), HTN ($\chi^2 = 4.55$, $p = 0.103$), dyslipidemia ($\chi^2 = 1.625$, $p = 0.444$), or fatty liver disease ($\chi^2 = 0.137$, $p = 0.934$) in those with documented CPAP compliance (use > 4 h per night on 70% of nights) vs. noncompliant CPAP patients. In those patients on CPAP, there was no association between CPAP compliance nor degree of OSA control (apnea hypopnea index, [AHI]) with age, BMI, serum glucose, serum insulin, adiponectin level, or HOMA-IR (Table 4 and Fig. 2). However, there was a strong trend for AHI to be negatively associated with HOMA-B ($r = -0.406$, $p = 0.076$) (Fig. 2).

4. Discussion

Obesity is associated with a large number of serious medical complications. The most common complications of obesity involve alterations in metabolic function that are risk factors for cardiovascular disease (CVD), namely insulin resistance, T2DM, fatty liver disease, dyslipidemia (increased serum TG and decreased serum HDL-cholesterol), and increased blood pressure (Klein et al., 2002). These metabolic complications have become a major public health problem due to the high prevalence of obesity and corresponding increases in the prevalence of obesity-related metabolic disease. These diseases thus have important health, quality-of-life and economic implications. However, not all obese persons develop metabolic complications, and ~25% of obese adults are “metabolically healthy” based on insulin sensitivity measured by the hyperinsulinemic-euglycemic clamp technique (Ferrannini et al., 1997; Brochu et al., 2001). Data from the 1994–2004 National Health and Nutrition and Examination Survey (NHANES) found that 32% of obese adults were metabolically healthy (MHO) when defined as having ≤ 1 cardio-metabolic abnormality (based on elevated blood pressure, HOMA-IR, plasma glucose, triglycerides and C-reactive protein (CRP) concentrations and low HDL-cholesterol levels) (Wildman et al., 2008). Accurate prediction and recognition of which patients are at greatest risk for complications,

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and understanding the mechanisms underlying this increased risk, is critical to public health policy and individual patient health.

Previous results from animal, clinical and epidemiological studies suggest that OSA exacerbates cardio-metabolic risk in obese patients, but findings have been inconsistent. In a case controlled study comparing 61 Caucasian males with newly diagnosed OSA and 43 control subjects without OSA, Coughlin and colleagues reported that OSA (defined by an AHI > 15), was independently associated with an increased prevalence of the metabolic syndrome as defined by the National Cholesterol Education Program (NCEP) criteria (3 of 5 of the following characteristics: abdominal obesity, raised triglycerides, reduced HDL cholesterol, elevated blood pressure, and raised plasma glucose). OSA was also independently associated with most individual metabolic parameters (Coughlin et al., 2004). In a study by Gruber et al., a similar independent association between OSA and metabolic syndrome components was observed; however insulin resistance (HOMA-IR) showed no independent association (Gruber et al., 2006). In a larger study with >250 Chinese subjects, there was an independent positive association between OSA and waist circumference, diastolic blood pressure, fasting glucose and the metabolic syndrome (Lam et al., 2006). Interestingly, a Japanese study found an independent association between OSA and the metabolic syndrome in men, but not in women (Sasanabe et al., 2006). Several other retrospective chart review studies have also showed a higher prevalence of metabolic abnormalities in patients with OSA, with the respiratory disturbance index and measurements of sleeping oxygen saturation during sleep being associated with glucose intolerance by OGTT (independent of age, gender, body mass index, and waist circumference) (Punjabi et al., 2004) and the average degree of oxyhemoglobin desaturation (independent of adiposity) being associated with impairments in insulin sensitivity and fasting hyperglycemia (Stamatakis et al., 2008). In contrast to the above positive reports, a study on Indian men reported that OSA was not independently associated with any of the components of the metabolic syndrome, including hypertension, insulin resistance and dyslipidemia, and obesity itself was the major determinant of metabolic aberrations (Sharma et al., 2007). Therefore, it has been a challenge to determine if OSA is an independent CV risk factor or if it is an obesity epiphenomenon, and no studies to date have examined the role of OSA in determining the MAO and MHO phenotypes.

How OSA may contribute to CV risk is unknown, but several postulated mechanisms have been proposed. The first mechanism is sleep fragmentation due to significant changes in habitual sleep duration that can lead to chronic low-grade systemic inflammation and activation of pro inflammatory pathways (Patel et al., 2009). Systemic Inflammation leads to up-regulation in the expression of adhesion molecules (El-Solh et al., 2002; Zamarron-Sanz et al., 2006) and OSA patients exhibit increased levels of inflammatory mediators such as tumor necrosis factor-alpha (TNFα) and Interleukin (IL)-6 (Imagawa et al., 2004; Bravo Mde et al., 2007). The second mechanism is via enhanced sympathetic activity that leads to up-regulation of the renin-angiotensin system and down-regulation of nitric oxide synthases (Prabhakar et al., 2001). The third mechanism proposes that OSA is an oxidative stress disorder. Oxidative stress can profoundly regulate the cellular transcriptome through activation of transcription factors, including specificity protein-1, hypoxia-inducible factor-1, c-jun kinase, and possibly the inflammatory NF-κB pathway. Activation of redox-

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sensitive gene expression is suggested by the increase in protein products of these genes, including vascular endothelial growth factor (Teramoto et al., 2003), erythropoietin (Marrone et al., 2008), and endothelin1 (Belaidi et al., 2009). In addition, low oxygen tension is a trigger for activation of polymorph nuclear neutrophils, which adhere to the endothelium (Dyugovskaya et al., 2002). Animal studies have suggested a causal role for intermittent hypoxia in insulin resistance, with lean C57BL/6J mice developing insulin resistance acutely after several hours of hypoxic exposure (Iiyori et al., 2007). Chronic intermittent hypoxia also exacerbates fasting hyperglycemia, glucose intolerance, and insulin resistance in both mice with diet-induced obesity and mice with genetic obesity (Iiyori et al., 2007; Drager et al., 2011; Polotsky et al., 2003). Thus, animal data suggest that the intermittent hypoxia with OSA in association with obesity may interact to cause metabolic dysfunction associated with decreased glucose utilization by oxidative muscle fibers, but that it occurs independently of activation of the ANS. The role of intermittent hypoxia in metabolic dysregulation has also been shown in humans as healthy volunteers exposed to 6 h of intermittent hypoxia develop insulin resistance (Punjabi et al., 2002).

In our study, we aimed to assess the relationship of OSA and treatment compliance and the risk of cardio-metabolic disease and metabolic health. Our results indicate that obese subjects with OSA have higher rates of HTN, higher fasting glucose, hyperinsulinemia and are more insulin resistant compared to obese patients without OSA; however, these abnormalities were accounted for by advanced age, gender differences, and higher BMI alone, independent of the presence or absence of OSA. Similarly, MAO patients were on average older and heavier and more likely to have OSA compared to MHO patients and exhibit trends for higher fasting glucose, insulin and HOMA-IR levels; but these differences were again accounted for by age, gender and BMI differences. Plasma adiponectin levels were also not different based on metabolic health ($p = 0.852$). However, HOMA-B was significantly greater in MAO subjects, with a trend for higher HOMA-B ($p = 0.086$) even after adjusting for demographic differences.

Since CPAP compliance can mitigate hypoxemia and reduce sleep disruption (which can theoretically attenuate the relationship to metabolic abnormalities), we did further sub analysis on patients stratified by 1) CPAP compliance and 2) a measure of OSA control (AHI). In fact, previous data indicates that treating OSA with CPAP can reverse multiple components of the metabolic syndrome. Results from a nonrandomized, observational study showed CPAP therapy reduced several components of the metabolic syndrome including blood pressure, triglyceride levels, and glucose levels, compared with patients with low adherence to CPAP (Dorkova et al., 2008). A second crossover, double-blind, randomized study exploring the impact of a three month treatment with CPAP, demonstrated that CPAP use was associated with significant mean decreases in blood pressure, lipids, glycated hemoglobin, BMI and visceral adiposity. Furthermore, the prevalence of metabolic syndrome was significantly reduced after CPAP therapy (13% vs. 1%). However, conflicting treatment-related effects on insulin sensitivity and hemoglobin A1c have also been seen. Coughlin and colleagues studied 34 obese subjects with OSA, but without overt cardio-metabolic disease (27 of whom were classified as having the metabolic syndrome), in a randomized, crossover, placebo-controlled study. They found that 6 weeks of active CPAP treatment reduced waking blood pressure, but did not produce any improvements in insulin

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resistance or serum lipids, nor decreased the proportion of subjects classified as having the metabolic syndrome (Coughlin et al., 2007). In our study, as in the overall group, there was no difference in the prevalence of T2DM, hyperlipidemia, or fatty liver disease in compliant vs. non-compliant patients, nor in those with well-controlled disease vs. those with poor control. We also found no association with insulin resistance based on CPAP compliance or control. Interestingly, there was a strong trend for a decline in β-cell function with increasing AHI that requires further investigation. In fact, a recent study found that HOMA-β was negatively correlated with AHI in young obese subjects (Gu et al., 2016), a phenomenon that was attributed to sleep apnea related oxygen desaturation. However, it remains uncertain whether this association was independent of BMI.

Our study has several important limitations. As a retrospective chart review, all data was not available for every subject, most importantly duration of OSA and detailed CPAP reports. Thus we were unable to account for duration of sleep apnea, which may have an important impact on metabolic status. In addition, the quantitative number of subjects which were included in the CPAP compliance and OSA severity analyses were limited by the availability of relevant data. As a retrospective study, we were also unable to provide any direct causal mechanistic insight into the metabolically healthy obese phenotype. It is also possible that we were underpowered to detect some significant differences between groups; however, the clear lack of comparative and associative differences after adjustment for BMI, age, and gender make it unlikely that we have missed a clinically significant impact of OSA on the metabolic variables studied. Despite these limitations, our findings are noteworthy as the first study to examine OSA as an important determinant distinguishing the MHO vs. MAO phenotype.

5. Conclusion

In our study of obese patients prior to bariatric surgery, OSA is not independently associated with overall cardio-metabolic health or the healthy obesity phenotype, even when accounting for CPAP compliance and AHI. The strongest predictors of overall metabolic health are age, gender, and BMI, so that with higher BMI, male gender, and more advanced age, individuals are more likely to develop a metabolically abnormal profile. However, the severity of OSA (as measured by AHI) may be independently predictive of β-cell function, and this augmented β-cell function may be a protective mechanism in OSA patients with the MHO phenotype. Our results thus indicate that the presence of OSA is not a significant predictor of the metabolically healthy obese (MHO) phenotype, but that further studies regarding the relationship between β-cell function, OSA, and metabolic health are warranted.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

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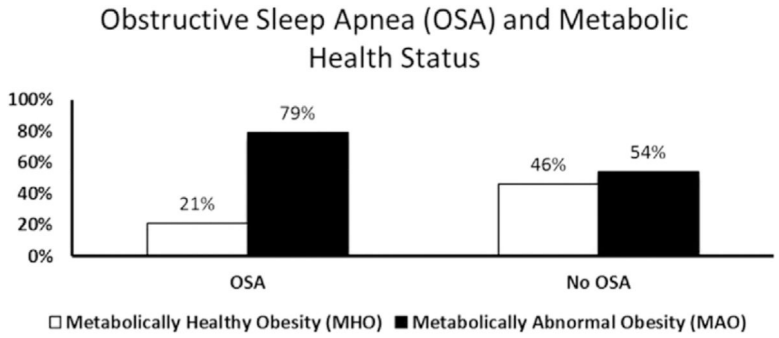

Fig. 1.

Obstructive Sleep Apnea (OSA) prevalence in the presence or absence of OSA. MHO: < 2 cardio-metabolic abnormalities. MAO: ≥ 2 cardio-metabolic abnormalities. MAO: Metabolically Abnormal Obese; MHO: Metabolically Healthy Obese.

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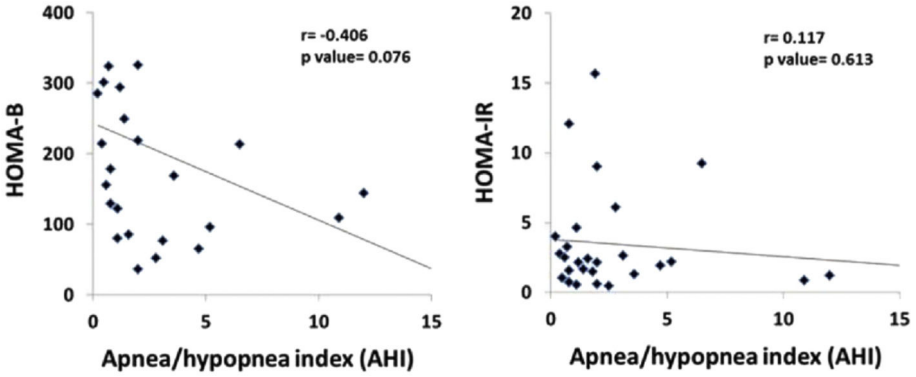

Fig. 2.

Correlation analyses between beta-cell function (HOMA-β) and insulin resistance (HOMA-IR) with AHI. HOMA-IR: homeostasis model assessment of insulin resistance; HOMA-β: homeostasis model assessment of beta-cell function; AHI: apnea hypopnea index.

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Table 1

Demographic Data for all patients and subdivided by obstructive sleep apnea (OSA) status.

	All Patients	No OSA	OSA	P-value
Subjects				
No (%)	83 (100)	26 (31)	57 (69)	0.019*
Gender				
Male No (%)	18 (22)	1 (6)	17 (94)	0.008*
Female No (%)	65 (78)	25 (39)	40 (61)	
Race				
White No (%)	70 (84)	21 (30)	49 (70)	0.574
African American No (%)	12 (15)	5 (42)	7 (59)	
Hispanic No (%)	1 (1)	0	1 (00)	
Age mean (SD)	45 (11)			
Min	33	40 (6)	48 (10)	0.005
Max	77			
BMI mean (SD)	49 (9)			
Min	33	44 (6)	51 (9)	0.002*
Max	77			
Diabetes/Prediabetes Diagnosis				
No (%)	43 (52)	10 (39)	33 (58)	0.100
Hypertension Diagnosis				
No (%)	52 (63)	11 (42)	41 (72)	0.010*
Dyslipidemia Diagnosis				
No (%)	63 (76)	18 (69)	45 (79)	0.337
Fatty Liver Disease Diagnosis				
No (%)	6 (7)	1 (4)	5 (9)	0.422
Abnormal Liver Enzymes				
No (%)	13 (16)	3 (12)	10 (18)	0.487
Obesity Class No (%)				
I	2 (2.4)	0	2 (2)	0.080
II	10 (12)	6 (7)	4 (5)	
III	73 (86)	20 (24)	51 (61)	
Metabolic Profile				
MAO	59 (71)	14 (17)	45 (54)	0.019*
MHO	24 (21)	12 (14)	12 (14)	

*Statistically significant difference between patients with OSA and those without OSA, $p<0.05$.

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Table 2

Metabolic parameters in those with and without Obstructive Sleep Apnea (OSA) diagnosis. HOMA-IR: Homeostasis Model Assessment of Insulin Resistance; HOMA-β: Homeostasis Model Assessment of β-cell Function.

	No OSA		OSA		P-value	
	Mean	**SD**	**Mean**	**SD**	**Unadjusted**	**Adjusted for age, BMI, gender**
Age (years)	38.04	9.24	48.25	10.23	0.000[a]	
BMI (kg/m^2)	44.24	6.25	50.38	9.02	0.003[a]	
Glucose (mg/dL)	78.55	10.85	91.51	22.29	0.003[a]	.314
Insulin level (μIU/mL)	8.16	4.62	14.72	11.87	0.002[a]	.350
Adiponectin (ng/mL)	6848.24	3793.31	6265.75	2651.46	0.474	
HOMA-IR	1.63	1.05	3.33	3.18	0.002[a]	.281
HOMA-β	177.64	217.32	235.03	176.53	0.300	

[a]Statistical significant p value.

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Table 3.

Demographic Data in metabolically abnormal obese (MAO) and metabolically healthy obese (MHO) patients. OSA: obstructive sleep apnea.

	MAO	MHO	P-value
Subjects			
No (%)	61 (71.8)	24 (21.2)	
Gender			
Male No (%)	15 (17.6)	3 (24.7)	0.219
Female No (%)	46 (54.1)	21 (3.5)	
Race			
White No (%)	52 (61.2)	20 (23.5)	0.758
Black African American No (%)	8 (9.4)	4 (4.7)	
Hispanic No (%)	1 (12.1)	0	
Age (years) mean (SD)	47 (11)	40 (9)	0.04 *
BMI (kg/m^2) mean (SD)	50 (9)	45 (7)	0.04 *
Diabetes/Pre diabetes diagnosis			
No (%)	40	5	0.000 *
Hypertension diagnosis			
No (%)	50	3	0.000 *
Dyslipidemia diagnosis			
No (%)	55	10	0.000 *
Fatty Liver Disease diagnosis			
No (%)	7	0	0.183
Abnormal liver enzymes diagnosis			
No (%)	11	4	1.0
Obesity class			
I	1 (1.2)	1 (1.2)	0.195
II	5 (5.9)	5 (5.9)	
III	55 (64.7)	18 (21.2)	
OSA diagnosis			
No (%)	45 (54.2)	12 (14.5)	.019 *
Glucose (ng/mL)	90 (23)	83 (14)	0.143
Insulin (μIU/mL)	14 (11)	10 (7)	0.050 *
Adiponectin (ng/dL)	6384 (3197)	6586 (2437)	0.834
HOMA-IR	3.2 (3)	2.1 (2)	0.130
HOMA-β	252 (200)	144 (130)	0.017 *

*Statistically significant difference between MAO and MHO patients, $p<0.05$.

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Table 4

Correlation analyses of continuous positive airway pressure (CPAP) compliance and apnea-hypopnea index (AHI) vs. demographic and metabolic parameters.

	CPAP compliance		Apnea Hypopnea Index (AHI)	
	Correlation coefficient (r)	**P value**	**Correlation coefficient (r)**	**P value**
BMI	0.082	0.662	−0.137	0.32
Age	0.032	0.847	0.237	0.171
Glucose	0.12	0.576	−0.116	0.617
Insulin	0.12	0.575	−0.004	0.987
Adiponectin	0.303	0.141	−0.172	0.443
HOMA-IR	0.13	0.545	0.117	0.613
HOMA-B	0.034	0.878	−0.406	0.076

CPAP compliance: use of CPAP more than 70% of nights. r: correlation coefficient.