

**“PREVALENCE AND CORRELATES OF PULMONARY
HYPERTENSION IN PATIENTS WITH SLEEP APNEA
SYNDROME-AN OBSERVATIONAL STUDY.”**

By

REG NO.: BR0122003

Dissertation

*Submitted to the
KLE University Belagavi, Karnataka
In partial fulfillment
Of the requirements for the degree of*

DOCTOR OF MEDICINE (M.D)

In

RESPIRATORY MEDICINE

J. N. MEDICAL COLLEGE, NEHRU NAGAR


BELAGAVI-590010

SEPTEMBER/OCTOBER- 2025


**KLE UNIVERSITY, BELAGAVI,
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**Professor & HOD
Dept. of Respiratory Medicine
J. N. Medical College, Belagavi.**
DR BHAGYASHRI PATIL MD,
Professor and Head,
Department of Respiratory
Medicine,
J.N. Medical College,
Nehru Nagar, Belagavi- 590010

Date: 1/4/25
Place: Belagavi


Dr. N. S. MAHANTASHETTI MD
Principal,
J.N. Medical College,
Nehru Nagar,
Belagavi- 590010
**PRINCIPAL
Jawaharlal Nehru Medical College
BELAGAVI**

Date: 1/4/25
Place: Belagavi

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Accredited 'A+' Grade by NAAC (3rd Cycle)

Placed in Category 'A' by MoE (GoI)

0831-2471350

Nehru Nagar, Belagavi- 590 010, Karnataka, INDIA

0831-2470759

www.inmc.edu

principal@inmc.edu

Ref No: MDC/PG/


Date: 01-04-2025

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Principal,
J. N. Medical College, Belagavi.

To,
Reg. No. BR0122003
Postgraduate Student,
2022-23 Batch,
Department of Respiratory Medicine
J. N. Medical College, Belagavi.



K.L.E. ACADEMY OF HIGHER EDUCATION AND RESEARCH
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JNMC INSTITUTIONAL ETHICS COMMITTEE
JAWAHARLAL NEHRU MEDICAL COLLEGE,
NEHRU NAGAR, BELAGAVI-590010 (KARNATAKA-INDIA)

Website: <http://www.jnmc.edu>
E-Mail : dome@jnmc.edu

Phone: (+91-(0)831 Office : 2472550
Principal: 2471701
Fax No. +91 (0)831 – 2470759

Ref No.MDC/JNMCIEC/ 130

Date: 30/03/2023

To,

REG NO.: BR0122003

PG Student in Respiratory Medicine
J. N. Medical College,
BELAGAVI.

Sub: Institutional Ethical Clearance for the study.

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(Dr. Smita Sonoli)
Member Secretary
JNMC Institutional Ethics Committee
J.N.Medical College, Belagavi.

(Dr. Harsha Hegde)
Chairman,
JNMC Institutional Ethics Committee
J.N.Medical College, Belagavi

ABBREVIATIONS LIST

S.No	Abbreviation	Full Form
1	SAS	Sleep Apnea Syndrome
2	OSA	Obstructive Sleep Apnea
3	PH	Pulmonary Hypertension
4	mPAP	mean Pulmonary Artery Pressure
5	WHO	World Health Organisation
6	SDB	Sleep Disordered Breathing
7	PAP	Positive Airway Pressure
8	AASM	American Academy of Sleep Medicine
9	SRS	Sleep Research Society
10	NREM	Non Rapid Eye Movements
11	REM	Rapid Eye Movements
12	EEG	Electroencephalography
13	RERA	Respiratory Effort Related Arousal
14	AHI	Apnea Hypopnea Index
15	RDI	Respiratory Disturbance Index
16	ODI	Oxygen Desaturation Index
17	ICSD	International Classification of Sleep Disorders
18	CSA	Central Sleep Apnea
19	RLS	Restless Legs Syndrome
20	PLMD	Periodic Limb Movement Disorder
21	SRBD	Sleep Related Breathing Disorders
22	OHS	Obesity Hypoventilation Syndrome

23	PaCO ₂	Partial Pressure of Carbon dioxide in arterial blood
24	GBD	Global Burden of Disease
25	BMI	Body Mass Index
26	Pcrit,P	Pharyngeal Critical Closing Pressure
27	ESS	Epworth Sleepiness Scale
28	PSG	Polysomnography
29	HSAT	Home Sleep Apnea Testing
30	COPD	Chronic Obstructive Pulmonary Disease
31	CPAP	Continuous Positive Airway Pressure
32	APAP	Auto-adjusting Positive Airway Pressure
33	AVAPS	Average Volume Assured Pressure Support
34	MAD	Mandibular Advancement Devices
35	nEPAP	Nasal Expiratory Positive Airway Pressure
36	UA	Upper Airway
37	FDA	Food and Drug Administration
38	PDE5	Phosphodiesterase type 5
39	UPPP	Uvulopalatopharyngoplasty
40	ANP	Atrial Natriuretic Peptide
41	BP	Blood Pressure
42	NF- $\kappa\beta$	Nuclear Factor Kappa B
43	RHC	Right Heart Catheterization
44	PAH	Pulmonary Arterial Hypertension
45	CTEPH	Chronic Thromboembolic Pulmonary Hypertension
46	ILD	Interstitial Lung Disease

47	FEV1	Forced Expiratory Volume in 1 second
48	PAWP	Pulmonary Artery Wedge Pressure
49	CO	Cardiac Output
50	PVR	Pulmonary Vascular Resistance
51	ERS	European Respiratory Society
52	HFpEF	Heart Failure with Preserved Ejection Fraction
53	ACC	American College of Cardiology
54	AHA	American Heart Association
55	ICS	Indian Chest Society
56	CSI	Cardiology Society of India
57	AIIMS	All India Institute of Medical Sciences
58	TTE	Transthoracic Echocardiography
59	TRV	Tricuspid Regurgitation Velocity
60	RV	Right Ventricle
61	RA	Right Atrium
62	PAT	Pulmonary Acceleration Time
63	PASP	Pulmonary Artery Systolic Pressure
64	ECHO	Echocardiography
65	EOG	Electrooculography
66	ECG	Electrocardiography
67	2D-TTE	Transthoracic Two Dimensional Echocardiography
68	RAP	Right Atrial Pressure
69	IVC	Inferior Vena Cava
70	TR	Tricuspid Regurgitation

71	VTI	Velocity time integral
72	LVOT	Left Ventricular Outflow Tract
73	HR	Heart Rate
74	HTN	Hypertension
75	T2DM	Type 2 Diabetes Mellitus
76	IHD	Ischemic Heart Disease
77	CKD	Chronic Kidney Disease
78	OCD	Obsessive Compulsive disorder
79	OAHl	Obstructive Apnea Hypopnea Index
80	PaO ₂	Partial pressure of Oxygen in arterial blood
81	SpO ₂	Saturation of peripheral Oxygen
82	IPAP	Inspiratory Positive airway Pressure
83	EPAP	Expiratory Positive Airway Pressure
84	WSPH	World Symposium on Pulmonary Hypertension

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ABSTRACT

Background:

Sleep apnea syndrome (SAS), primarily manifesting as obstructive sleep apnea (OSA), is a common disorder associated with recurrent upper airway obstruction, intermittent hypoxemia, and sleep fragmentation. OSA affects 9–38% of adults and is linked to cardiovascular comorbidities, including pulmonary hypertension (PH). PH, defined by a mean pulmonary arterial pressure (mPAP) >20 mmHg (≥ 25 mmHg in earlier studies), occurs in 17–42% of OSA patients. Its mechanisms involve intermittent hypoxia, sympathetic overactivity, and vascular remodeling. PH in OSA worsens prognosis, but positive airway pressure (PAP) therapy may partially reverse PH, highlighting the need for early detection and management.

Aim and Objective:

The primary objective of this study is to determine the prevalence of pulmonary hypertension in patients with sleep apnea syndrome. The secondary objective is to evaluate the severity of pulmonary hypertension correlation with the severity of sleep apnea syndrome and to identify various risk factors associated with pulmonary hypertension in sleep apnea syndrome.

Materials and Methods :

Following Institutional Ethics Committee approval, this study was conducted at KLE'S Dr. Prabhakar Kore Charitable Hospital and Medical Research Center, Belagavi. Suspected sleep apnea syndrome (SAS) patients were screened, and those meeting inclusion criteria were enrolled after informed consent. A structured protocol

including clinical history, physical examination, and screening tools (Modified Mallampati Score, Epworth Sleepiness Scale, STOP-BANG) was used. All participants underwent overnight polysomnography (Philips Resironics Alice PDX) as per AASM guidelines, with OSA diagnosed based on Apnea-Hypopnea Index (AHI ≥ 5). Severity was classified as mild (AHI 5–14), moderate (15–29), and severe (≥ 30). Transthoracic echocardiography (Philips EPIQ 7C) was performed to assess right atrial pressure (RAP) and pulmonary artery systolic pressure (PASP) using Doppler-derived calculations. PH severity was classified as mild (30–45 mmHg), moderate (46–65 mmHg) and severe (>65 mmHg).

Results:

A total of 70 OSA patients were included, stratified into mild (n=12), moderate (n=18), and severe (n=40) groups. The overall prevalence of pulmonary hypertension (PH) was 30%, with PH severity increasing significantly with OSA severity. Higher weight and BMI were observed in severe OSA (BMI: 35.14 ± 6.09). STOP-BANG and Modified Mallampati scores correlated with PH severity, while neck circumference was linked to PH but not OSA severity. Nocturnal and daytime SpO₂ showed significant associations with OSA and PH severity. A strong correlation was observed between OSA and PH across BMI groups. Common comorbidities included hypertension, ischemic heart disease, COPD, hypothyroidism, and type 2 diabetes mellitus, further emphasizing the need for early intervention.

Limitation:

This study relies on echocardiographic estimates for pulmonary hypertension (PH) diagnosis, which may lead to overestimation or underestimation compared to right

heart catheterization. As an observational, cross-sectional study, it identifies associations but cannot establish causality or track disease progression over time. Potential confounding factors, including obesity, smoking, and metabolic conditions, may influence results. Additionally, limited representation of pediatric and elderly populations may affect generalizability. The lack of longitudinal follow-up restricts insights into the long-term impact of sleep apnea on pulmonary circulation, highlighting the need for future prospective studies.

Conclusion:

This study reinforces the strong association between obstructive sleep apnea (OSA) and pulmonary hypertension (PH), emphasizing the impact of demographic, physiological, and comorbid factors. The progressive rise in PH severity with worsening OSA highlights the need for early diagnosis and intervention. Weight management, cardiovascular risk assessment, and CPAP therapy play key roles in reducing long-term complications. The significant link between comorbidities and PH underscores the importance of a multidisciplinary approach. Future research should explore long-term PH outcomes, treatment efficacy, and novel biomarkers for early detection, ultimately improving patient prognosis and quality of life.

INTRODUCTION

Sleep apnea syndrome (SAS), most commonly manifesting as obstructive sleep apnea (OSA), is a common respiratory disorder characterized by recurring cycles of partial or complete upper airway obstruction during sleep, causing frequent reductions in airflow and periodic nocturnal hypoxemia.¹ The resulting frequent sleep arousal that normally follows these events leads to disrupted sleep architecture and related daytime sleepiness, cognitive impairment, and reduced quality of life.² Worldwide, obstructive sleep apnea (OSA) has been estimated to affect 9–38% of adults, while even greater prevalence has been reported in patients with obesity or other comorbidities.³ Of note, sleep apnea is also closely associated with a broad array of cardiovascular and metabolic comorbidities,⁴ including systemic hypertension, coronary artery disease, cerebrovascular disease, and insulin resistance.⁵ Among its less well-documented but potentially severe complications is the development and worsening of pulmonary hypertension (PH).⁶

Pulmonary hypertension is a disorder of pathophysiologic significance defined by an increased mean pulmonary arterial pressure (mPAP) >20 mm Hg at rest, according to recent guidelines,⁷ although a threshold of ≥ 25 mm Hg has been employed in most classic studies.⁸ Pulmonary hypertension can be caused by a wide variety of etiologies and can be divided into five major categories based on the World Health Organization (WHO) classification and pulmonary hypertension secondary to OSA comes under Group III (PH secondary to hypoxemia and lung health).⁹

Regardless of etiology, PH significantly increases the workload on the right ventricle, most commonly causing right ventricular hypertrophy, remodeling, and, eventually, right-sided heart failure if untreated⁷. While the pathophysiologic

mechanisms differ based on the cause, the presence of chronic hypoxemia can be a powerful stimulus for elevated pulmonary artery pressures.¹⁰ Therefore, chronic respiratory disease and sleep-disordered breathing (SDB), including OSA, are key players in PH pathogenesis.¹¹

Over the last two decades, the intricate interplay between OSA and pulmonary vascular remodeling has received growing attention.¹² Various hypotheses were raised to justify the interplay. First, the intermittent hypoxemia characteristic of OSA evokes sympathetic overactivity, ultimately leading to vasoconstriction and remodeling of the pulmonary vasculature.³ Second, recurrent intrathoracic pressure variations during apneic events result in transient cardiac afterload increase and right ventricular strain.¹³ Third, OSA often coexists with other cardiometabolic risk factors such as obesity, systemic hypertension, and dyslipidemia, all of which can independently worsen vascular function.¹⁴ As a result, patients with OSA may develop not only systemic hypertension but also elevated pulmonary artery pressures, culminating in pulmonary hypertension.¹⁵

The exact prevalence of PH among patients with OSA remains variably reported in the literature, largely due to differences in diagnostic criteria, patient selection, and the severity of sleep apnea.¹⁴ Earlier studies suggested that 17–42% of patients with OSA exhibit pulmonary hypertension, although not all are clinically significant or symptomatic.^{16,17} Variations in study populations (e.g., inclusion of individuals with coexisting chronic obstructive pulmonary disease, heart failure, or interstitial lung disease) also complicate the estimation of true prevalence.¹⁸ Also the modality used to diagnose PH may affect the calculation of prevalence. Nevertheless, the convergence of recent data underscores that PH in OSA is neither uncommon nor

benign. Clinically, even mild elevations in pulmonary artery pressure can be associated with decreased exercise tolerance, worsening hypoxemia, and poorer overall prognoses.¹⁹ The combination of OSA and PH, therefore, demands a targeted approach to screening, evaluation, and management. Also there are studies which show that use of PAP devices for treatment of OSA will reverse PH to an extent ,thus further emphasizing not only the diagnosis of OSA and PH, but also the appropriate treatment for the same.

OBJECTIVES

Primary Objective:

- To determine the prevalence of pulmonary hypertension in patients with sleep apnea syndrome.

Secondary objective:

- To evaluate the severity of pulmonary hypertension correlation with the severity of sleep apnea syndrome.
- To identify various risk factors associated with pulmonary hypertension in sleep apnea syndrome.

REVIEW OF LITERATURE

SLEEP

Sleep is the intermediate state between wakefulness and death; wakefulness being regarded as the active state of all the animal and intellectual functions, and death as that of their total suspension¹. According to a simple behavioural definition, sleep is a reversible behavioural state of perceptual disengagement from an unresponsiveness to the environment.²⁰

IMPORTANCE OF SLEEP

Sleep is crucial for the health and well-being of individuals across all age groups. Healthy sleep promotes cognitive functioning, mood regulation, mental health, and cardiovascular, cerebrovascular, and metabolic health. Adequate sleep also reduces the risk of accidents and injuries due to sleepiness, such as workplace incidents and motor vehicle crashes. Sleep deprivation, circadian misalignment, and untreated sleep disorders have a significant negative impact on physical health, mental well-being, and public safety.²¹

Chronic sleep deprivation is linked to increased risks of mortality and medical conditions like cardiovascular disease, diabetes, obesity, and cancer. The American Academy of Sleep Medicine (AASM) and Sleep Research Society (SRS) recommend that adults sleep at least 7 hours per night, with 7 to 9 hours being optimal. Extending sleep duration for those who consistently sleep insufficiently may lead to health improvements. Healthy sleep requires adequate sleep duration, regularity, appropriate timing, the absence of sleep disorders, and good sleep quality.²¹

STAGES OF SLEEP

According to the American Academy of Sleep Medicine (AASM), sleep is divided into two major types:²²

1. Non-Rapid Eye Movement (NREM) Sleep
2. Rapid Eye Movement (REM) Sleep

NREM sleep is further divided into three stages, making a total of four sleep stages overall.

Stage	Name	Key Characteristics
N1	NREM Stage 1	Lightest stage of sleep; transition from wakefulness; slow eye movements; reduced muscle tone. EEG shows low voltage, mixed frequency.
N2	NREM Stage 2	Light sleep; presence of sleep spindles and K-complexes on EEG; further slowing of brain activity and body functions.
N3	NREM Stage 3 (Slow-Wave Sleep)	Deep sleep; also known as slow-wave sleep or delta sleep; important for physical restoration. EEG shows high amplitude delta waves.
REM	Rapid Eye Movement Sleep	Active brain in a paralyzed body; dreaming occurs; EEG resembles wakefulness; muscle atonia present. Critical for memory consolidation and emotional processing.

The adult sleep cycle lasts about 90–110 minutes and includes non-REM (N1, N2, N3) and REM sleep stages. Adults typically go through 4–6 cycles per night, with more deep sleep (N3) earlier in the night and more REM sleep toward morning. The

paediatric sleep cycle, especially in infants and young children, is shorter (about 50–60 minutes in infants). Newborns alternate mainly between active (REM-like) and quiet sleep, gradually developing distinct sleep stages with age. Children also spend more time in deep sleep compared to adults.²²

To approach a patient with sleep disorders by following nomenclature according to AASM:²²

Term	Definition
Apnea	A complete reduction in airflow by 90% or more for at least 10 seconds.
Obstructive Apnea	A type of apnea where breathing effort continues, but airflow is blocked.
Central Apnea	A pause in breathing with no respiratory effort during the event.
Mixed Apnea	A breathing pause that starts without effort and ends with effort against an obstruction.
Hypopnea	A partial reduction in airflow lasting 10 seconds or more, along with either a drop in oxygen levels ($\geq 3\%$) or an arousal from sleep.
Respiratory Effort-Related Arousal (RERA)	A breathing pattern showing increased effort that leads to sleep disruption but doesn't meet criteria for apnea or hypopnea.
Apnea-Hypopnea Index (AHI)	The number of apneas and hypopneas that occur per hour of sleep.
Respiratory Disturbance Index (RDI)	The hourly rate of apneas, hypopneas, and RERAs combined during sleep.
Oxygen Desaturation Index (ODI)	How many times per hour the blood oxygen level drops by at least 3% or 4%.
Hypoventilation	A condition where carbon dioxide in the blood rises

	above normal levels for a sustained period during sleep.
Cheyne-Stokes Breathing	A breathing pattern characterized by gradually increasing and decreasing effort followed by central apneas or hypopneas.
Sleep-Disordered Breathing (SDB)	A group of conditions involving abnormal breathing patterns or airflow limitations during sleep.
Arousal	A sudden shift in brain wave activity lasting at least 3 seconds, typically following stable sleep for 10 seconds or longer.

Classification of sleep disorder according to ICSD-3:²³

Category	Disorder Types
1. Insomnia Disorders	- Chronic Insomnia Disorder - Short-Term Insomnia - Other Insomnia
2. Sleep-Related Breathing Disorders	- Obstructive Sleep Apnea (OSA) - Central Sleep Apnea (CSA) - Sleep-Related Hypoventilation Disorders - Sleep-Related Hypoxemia Disorder - Isolated Snoring
3. Central Disorders of Hypersomnolence	- Narcolepsy Type 1 - Narcolepsy Type 2 - Idiopathic Hypersomnia - Kleine-Levin Syndrome - Insufficient Sleep Syndrome
4. Circadian Rhythm Sleep-Wake Disorders	- Delayed Sleep-Wake Phase Disorder - Advanced Sleep-Wake Phase Disorder - Irregular Sleep-Wake Rhythm Disorder - Non-24-Hour Sleep-Wake Rhythm Disorder - Shift Work Disorder - Jet Lag Disorder
5. Parasomnias	- NREM Parasomnias (Sleepwalking, Confusional Arousals, Sleep Terrors) - REM Sleep Behavior Disorder

	<ul style="list-style-type: none">- Nightmare Disorder- Sleep Enuresis- Sleep-Related Eating Disorder
6. Sleep-Related Movement Disorders	<ul style="list-style-type: none">- Restless Legs Syndrome (RLS)- Periodic Limb Movement Disorder (PLMD)- Sleep-Related Leg Cramps- Sleep-Related Bruxism- Propriospinal Myoclonus at Sleep Onset
7. Other Sleep Disorders	<ul style="list-style-type: none">- Isolated Symptoms and Normal Variants (e.g., Long Sleeper, Short Sleeper)- Unclassified Sleep Disorders

Among all the above mentioned sleep disorders, patients with sleep related breathing disorders are involved in this study. It is this group of disorders which has shown multiple adverse cardiovascular outcomes along with sleep disturbances.

Classification of Sleep-Related Breathing Disorders

(According to ICSD 3):

Sleep-Related Breathing Disorders (SRBDs) refer to a group of conditions characterized by abnormal respiration during sleep. These disorders are classified into the following categories based on the International Classification of Sleep Disorders – Third Edition (ICSD-3)²³

1. Obstructive Sleep Apnea Syndromes (Sleep Apnea Syndrome) Characterized by repetitive episodes of complete or partial upper airway obstruction during sleep, leading to reduced or absent airflow despite ongoing respiratory effort. It is the most common type of SRBD.²³ Note: According to ICSD-3, **Obstructive Sleep Apnea Syndromes is alternatively termed Sleep Apnea Syndrome.**²³

2. Central Sleep Apnea (CSA) Syndromes Defined by recurrent episodes of apnea and hypopnea during sleep resulting from diminished or absent respiratory drive, without upper airway obstruction. Common subtypes include Cheyne–Stokes breathing, high-altitude periodic breathing, and idiopathic CSA.²³

3. Sleep-Related Hypoventilation Disorders These involve decreased ventilation during sleep that leads to elevated arterial carbon dioxide levels (PaCO₂). This includes obesity hypoventilation syndrome (OHS), congenital central hypoventilation syndrome, and hypoventilation due to neuromuscular or chest wall disorders.²³

4. Sleep-Related Hypoxemia Disorder Characterized by oxygen desaturation that occurs only during sleep and is not attributable to apneas or hypoventilation. It typically occurs in the context of underlying cardiopulmonary disease.²³

5. Isolated Symptoms and Normal Variants (e.g., Primary Snoring) Refers to conditions such as habitual snoring in the absence of obstructive or central events.

While not associated with significant oxygen desaturation, primary snoring may contribute to sleep fragmentation and daytime symptoms.²³

Among all the sleep related breathing disorders, OSA is the most common disorder and is associated with cardiovascular comorbidities and as per the literature 9%-38% of patients have OSA.

OBSTRUCTIVE SLEEP APNEA:

Obstructive sleep apnea (OSA) is a sleep-related breathing disorder characterized by repeated episodes of partial or complete obstruction of the upper airway during sleep.²² These episodes, known as apneas or hypopneas, typically last at least 10 seconds and can lead to reduced blood oxygen saturation and disrupted sleep.

The classic signs and symptoms of OSA includes excessive daytime sleepiness, loud snoring, snorting and gasping at night (associated with apnea termination).Physical signs associated with OSA includes obesity, large neck circumference and crowding of the oropharynx.

OSA is an independent major risk factor for a number of associated medical conditions:⁴⁶

- All-cause mortality
- Systemic hypertension
- Stroke
- Myocardial infarction
- Sudden death at night
- Pulmonary hypertension
- Motor vehicle accidents
- Depression

- Congestive heart failure
- Obstructive lung diseases (asthma/chronic obstructive pulmonary disease)
- Cardiac dysrhythmias (especially atrial fibrillation)
- Type 2 diabetes mellitus/insulin resistance

The severity of OSA is commonly assessed using the Apnea-Hypopnea Index (AHI),²² which measures the average number of apneas and hypopneas per hour of sleep:

- Mild OSA: AHI of 5 to 15 events per hour
- Moderate OSA: AHI of 15 to 30 events per hour
- Severe OSA: AHI greater than 30 events per hour

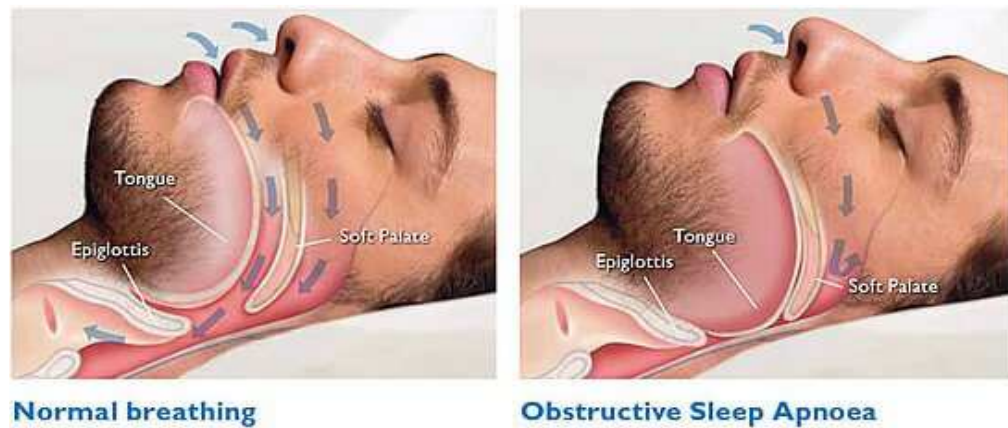


Figure.1- Normal Breathing vs. Obstructive Sleep Apnea

Epidemiology of Obstructive Sleep Apnea (OSA):

Obstructive Sleep Apnea (OSA) is a highly prevalent sleep disorder worldwide, characterized by repeated upper airway obstruction during sleep. Its prevalence varies across different populations due to factors such as age, gender, obesity, and geography.

Global Prevalence

A global study estimated that approximately 936 million adults aged 30–69 years have OSA, with 425 million suffering from moderate to severe forms.²⁵ These estimates highlight OSA as a significant public health issue with potential cardiovascular and metabolic consequences.

Prevalence in Asia

Studies in Asia have shown varying prevalence rates depending on population characteristics. Earlier studies reported that symptomatic OSA affects 4.1–7.5% of middle-aged men and 2.1–3.2% of middle-aged women.²⁶ However, more recent research suggests that the prevalence in some Asian countries, such as China, is much higher, reaching 23.6% in adults aged 30–69 years.²⁷

Prevalence in India

In India, the estimated prevalence of OSA varies widely, ranging from 3.7% to 21% in the general population.²⁸ A meta-analysis reported that approximately 104 million Indians suffer from OSA, with nearly 47 million experiencing moderate-to-severe forms.²⁹ The rising burden of OSA in India can be attributed to increasing obesity rates, lifestyle changes, and improved diagnostic awareness.

OSA is more prevalent in males compared to females, with a male-to-female ratio of approximately 2:1 to 3:1.³⁰ However, postmenopausal women have an increased risk due to hormonal changes, bringing their prevalence closer to that of men. Age is an important factor influencing OSA prevalence. In pediatric populations, OSA affects approximately 1–5% of children³¹. In elderly individuals, the prevalence is significantly higher, with estimates ranging from 40–60%.³² These variations highlight the need for age-specific diagnostic and management strategies. Studies indicate that OSA is more prevalent in urban populations compared to rural areas,

likely due to higher rates of obesity, sedentary lifestyles, and environmental factors such as pollution. Further research is needed to understand these differences in the Indian context. Obesity is one of the strongest risk factors for OSA. As obesity rates continue to rise globally, the burden of OSA is also expected to increase. Data from the Global Burden of Disease (GBD) study suggest that obesity-related OSA is an emerging public health crisis, especially in developing countries.³³

Risk Factors³⁴

- Obesity (BMI >30 kg/m²)
- Neck size (collar size >17 inches in males, >16 inches in females)
- Gender (male/female 2–3:1)
- Genetic factors/family history
- Upper airway and craniofacial anatomy
- Macroglossia
- Lateral peritonsillar narrowing Elongation/enlargement of the soft palate
- Tonsillar hypertrophy
- Nasal septal deviation
- Retrognathia, micrognathia
- Narrowing of the hard palate
- Class III/IV modified Mallampati airway
- Specific genetic disorders, e.g., Treacher Collins, Down syndrome, Apert syndrome
- Endocrine disorders, e.g., hypothyroidism, polycystic ovarian syndrome, acromegaly
- Alcohol, sedative, or hypnotic use

PATHOGENESIS OF OBSTRUCTIVE SLEEP APNEA

OSA is driven by a multifaceted and complex set of mechanisms, with significant inter-individual variability and many aspects still not fully understood.³⁵ The development of obstructive sleep apnea (OSA) is influenced by both structural and neurological factors. The upper airway, extending from the posterior nasal septum to the larynx, lacks substantial bony support and is composed of four segments: the nasopharynx, retropalatal oropharynx, retroglossal oropharynx, and hypopharynx. The airway's boundaries are formed by soft tissues such as the soft palate and tongue, as well as pharyngeal constrictor muscles, lymphoid structures, parapharyngeal fat pads, and the mandibular rami.

Upper airway structural anomalies represent a principal contributor to OSA. Nearly all patients with the condition demonstrate varying degrees of upper airway narrowing or collapse due to soft tissue overgrowth or bony deformities.³⁶ These structural issues may involve relative narrowing caused by fat accumulation (often related to obesity) or absolute stenosis due to craniofacial skeletal abnormalities—both of which are significant causes of airway collapse.

During sleep, airway collapse leads to a reduction in the airway diameter, increasing resistance and resulting in apneic and hypopneic episodes typical of OSA. Structural characteristics of the retropalatal and retroglossal regions—particularly the surrounding soft tissues and craniofacial features—contribute to airway morphology and its susceptibility to collapse. Anatomical factors thus play a critical role in determining the likelihood of airway collapse. Additionally, upper airway neuromuscular control has gained recognition as a vital factor in OSA pathophysiology.

As research has progressed, it is increasingly acknowledged that both anatomical and functional factors contribute to the collapse of the upper airway.

Based on this understanding, the PALM model has been proposed to describe OSA pathogenesis. This model incorporates four elements: pharyngeal critical closing pressure (Pcrit, P), a reduced arousal threshold (A), elevated loop gain (L), and impaired upper airway dilator muscle responsiveness (M) (Fig. 2a). These interacting mechanisms collectively influence OSA development (Fig. 2b). The following sections will explore these key pathophysiological contributors and how they shape the current understanding of OSA pathogenesis.³⁷

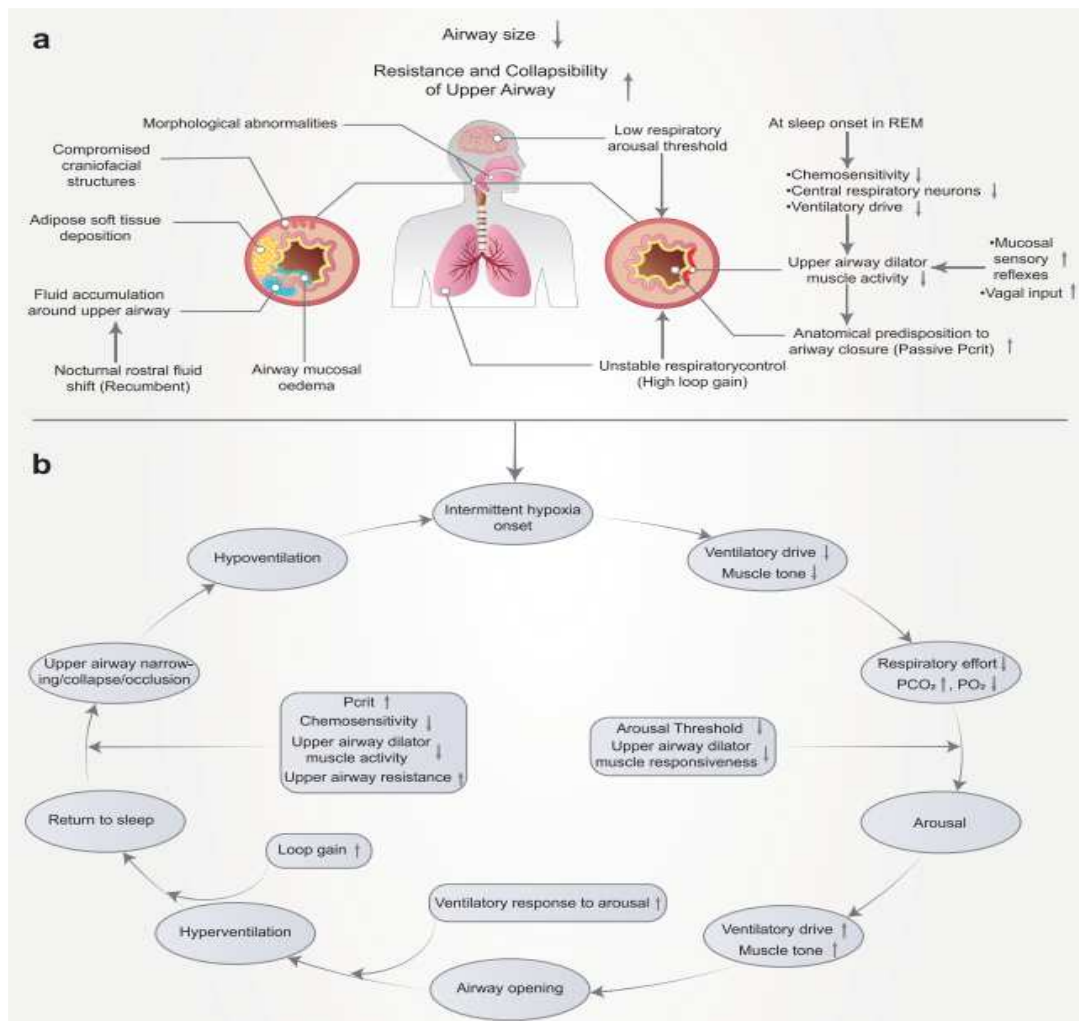


Figure.2- Mechanisms of the pathogenesis of OSAS³⁸

Morphological abnormalities are among the most prevalent factors leading to OSA. In adults, features such as shortened mandibular length, a low-lying hyoid bone,

posteriorly positioned maxilla, and pharyngeal space constriction contribute to oral cavity crowding.³⁹ Craniofacial syndromes like Pfeiffer, Pierre Robin, Crouzon, and Apert—which involve midface hypoplasia or craniosynostosis—are also associated with increased OSA risk.⁴⁰ Enlargement of soft tissues surrounding the airway is another common cause of pharyngeal narrowing⁴¹. Examples include an elongated soft palate, retrognathia, macroglossia, hypertrophied tonsils, excessive neck tissue, and redundant pharyngeal mucosa. While the soft palate and tongue compromise the airway's anterior-posterior dimensions, thickened pharyngeal walls reduce its lateral diameter—an important site of collapse in many OSA patients.⁴²

Obesity, which is highly prevalent in OSA patients, significantly contributes to upper airway compression through increased fat deposits in the pharyngeal region and thoracic cavity. These fat deposits exacerbate airway narrowing and may promote OSA development. Tongue morphology may also be a contributing factor; studies have shown that the shape of the tongue differs between OSA patients and healthy controls, particularly in the supine position. Additionally, fluid retention and redistribution, termed nocturnal rostral fluid shift, may play a role in OSA pathogenesis. This phenomenon involves the passive movement of fluid from the lower limbs to the upper body during recumbency, driven by hydrostatic and colloid osmotic pressure gradients.⁴³ The degree of airway collapsibility can be quantified using measurements such as Pcrit.

Loop Gain

Loop gain refers to the stability of the respiratory control system and represents how strongly the body responds to disturbances in ventilation. It consists of three main components: controller gain (the ventilatory response to changes in blood gases), plant gain (the effect of ventilation on gas exchange), and feedback delay (the

time between a change in ventilation and its sensed effect). In individuals with OSA, a high loop gain results in exaggerated ventilatory responses to minor changes in oxygen or carbon dioxide levels. This can create a cycle where hyperventilation following an apnea reduces carbon dioxide below the threshold needed to maintain breathing, leading to further apneas or hypopneas. Such instability contributes to recurrent airway collapse and sleep fragmentation.⁴⁴

Neural Modulation of Upper Airway Patency

The neural modulation of upper airway patency during sleep involves a complex interaction between neurotransmitters and muscle activity, particularly the genioglossus muscle, which plays a key role in maintaining airway openness. During sleep, the balance of transpharyngeal pressure shifts toward airway collapse due to reduced activity of upper airway dilator muscles, especially during REM sleep. This reduction in muscle activity increases the risk of airway obstruction.³⁴

There are three main neural mechanisms that influence the vulnerability of the upper airway to collapse:

1. **Reflex Activation:** Negative airway pressure detected by laryngeal mechanoreceptors activates the genioglossus via the hypoglossal nerve, but this reflex is weaker during non-REM and further diminished during REM sleep, increasing the risk of collapse.³⁴
2. **Respiratory Drive:** Upper airway muscle activity is responsive to respiratory control from the medulla. When respiratory drive is unstable, reduced muscle activity can contribute to airway collapse.³⁴
3. **Arousal Mechanisms:** Neural circuits involved in arousal (serotonergic and noradrenergic) provide tonic excitatory input to the genioglossus. During sleep, there is reduced excitatory output, but arousals from sleep in response to

respiratory disturbances can help restore airway patency. However, OSA patients often have a diminished ability to recover ventilation without cortical arousals.³⁴

In summary, these neural mechanisms contribute to the pathophysiology of OSA by reducing muscle activity and reflex responses that would otherwise maintain airway patency during sleep.

Signs and symptoms of Obstructive Sleep Apnea Syndrome:⁴⁵

- **Severe snoring, snoring, gasping, or choking in sleep**
- **Witnessed apneas in sleep**
- **Excessive daytime sleepiness;** tendency to fall asleep in inappropriate situations (e.g., while driving, attending lectures)
- **Lack of energy**
- **Morning headaches**
- **Large neck size:** 17 inches in men, 16 inches in women
- **Crowding of the oropharynx:** Mallampati score of 3 or greater, large tonsils, large tongue, elongated uvula
- **Facial abnormalities:** retrognathia, midface deformities
- **Obesity** (body mass index >30)
- **Nocturnal gastroesophageal reflux**
- **Impotence; erectile dysfunction**

Screening tools for OSA:

Several standardized tools have been developed to screen for obstructive sleep apnea (OSA). A recent review by a task force from the American Academy of Sleep Medicine evaluated 29 available screening tools to assess their reliability, efficacy, and feasibility in clinical settings. No single tool is universally recommended. However, multiple screening tools are used, and while they are not perfect, they can

be helpful when combined with clinical criteria to assess the risk for OSA in adults. In addition to screening for epworth sleepiness scale (ESS), the STOP-BANG questionnaire is also considered useful for screening OSA in adult patients.⁴⁶

The screening tools which are used in our studies are follows:

- Modified mallampati score
- epworth sleepiness scale
- STOP-BANG questionnaire

Modified Mallampati score

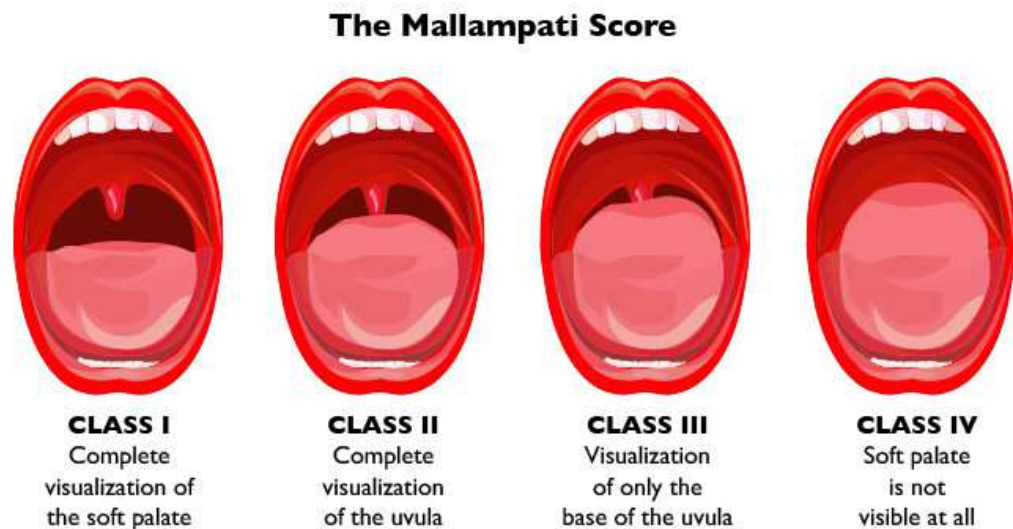


Figure.3 - Modified Mallampati score

STOP-BANG questionnaire:

The mnemonic STOP- BANG includes the following:⁴⁶

- S: “Do you snore loudly, loud enough to be heard through a closed door?”
- T: “Do you feel tired or fatigued during the daytime almost every day?”
- O: “Has anyone observed that you stop breathing during sleep?”
- P: “Do you have a history of high blood pressure with or without treatment?”
- B: BMI > 35 kg/m²

- A: Age > 50 years
- N: Neck circumference > 43 cm (17 in)
- G: Gender, male

When more than three items are positive, the sensitivity and specificity for OSA are 87% and 31%, respectively.

Epworth sleepiness scale:

In contrast to just feeling tired, how likely are you to doze off or fall asleep in the following situations? (This refers to your usual life in recent times. Even if you have not done some of these things recently, try to work out how they would have affected you.) Use the following scale to choose the most appropriate number for each situation:

0 = Would never doze
1 = Slight chance of dozing
2 = Moderate chance of dozing
3 = High chance of dozing

Situation	Chance of Dozing
Sitting and reading	_____
Watching TV	_____
Sitting inactive in a public place (i.e., a theater or a meeting)	_____
As a passenger in a car for an hour without break	_____
Lying down to rest in the afternoon when circumstances permit	_____
Sitting and talking to someone	_____
Sitting quietly after lunch without alcohol	_____
In a car, while stopping for a few minutes in traffic	_____

Figure. 4- Epworth sleepiness scale³⁴

The Epworth Sleepiness Scale, a questionnaire for assessing the degree of subjective sleepiness, is usually elevated in sleep apnea patients (scored 0–24, with >10 considered abnormal).³⁴

Diagnosis of OSA:

According to the American Academy of Sleep Medicine (AASM), the gold standard for diagnosis is polysomnography (PSG) conducted in a sleep laboratory, assessing airflow, oxygen saturation, respiratory effort, and EEG patterns. Home sleep apnea testing (HSAT) is recommended for high-risk OSA patients but not for those with suspected CSA or comorbidities like COPD or heart failure.⁴⁷ AASM criteria confirm OSA if $AHI \geq 5$ with symptoms or $AHI \geq 15$ regardless of symptoms.

Diagnostic Criteria for Obstructive Sleep Apnea (OSA) :

A diagnosis of OSA is established when either (**A and B**) or **C** is met:

A. At least one of the following symptoms is present:

1. The patient reports symptoms such as excessive daytime sleepiness, fatigue, insomnia, or other issues that impair sleep-related quality of life.
2. The patient experiences awakening episodes with breath-holding, gasping, or choking.
3. A bed partner or another observer notes habitual snoring or noticeable interruptions in breathing during the patient's sleep.²³

B. Sleep study findings (via Polysomnography [PSG] or Home Sleep Apnea Testing [HSAT]) show:

1. Five or more predominantly obstructive respiratory events per hour of sleep (in PSG) or per hour of recording time (in HSAT). These events include obstructive apneas, mixed apneas, hypopneas, or respiratory effort-related arousals (RERAs).²³

OR

C. Sleep study (PSG or HSAT) demonstrates:

1. Fifteen or more predominantly obstructive respiratory events (including obstructive and mixed apneas, hypopneas, or RERAs) per hour of sleep (PSG) or monitoring (HSAT), regardless of symptoms.²³

Levels of Sleep studies:

Sleep testing is currently classified into levels of complexity.

- Level 1 is the classic in- laboratory full PSG as discussed previously, including measures of airflow, respiratory effort, oxygenation, electroencephalogram, electrooculogram, and electromyogram, to allow for sleep staging.⁴⁶
- Level 2 is an out- of- laboratory portable study essentially equivalent to the in- laboratory study (minimum of seven parameters).⁴⁶
- Level 3 is an unattended portable recording measuring at least four channels: heart rate, oxygen saturation, airflow, respiratory effort, but no sleep staging.⁴⁶
- Level 4 is an unattended portable study, measuring a minimum of three channels, such as heart rate, oxygen saturation, and respiratory analysis.⁴⁶

Conditions in Which Evaluation for Obstructive Sleep Apnea Should Be Considered:³⁴

- Obesity
- Systemic hypertension
- Myocardial infarction
- Cerebrovascular accident
- Type 2 diabetes mellitus
- Pulmonary hypertension
- Polycystic ovarian syndrome
- Atrial fibrillation
- Driver involved in a sleep-related automobile crash
- Preoperative anesthesia evaluation

Treatment for Obstructive Sleep Apnea (OSA)

Effective treatment in OSA requires a patient centered chronic disease diagnostic approach. It not only involves managing OSA , but also involves multiple therapeutic modalities associated with managing comorbidities, sleep disorders to optimize the therapy. The medical treatment for OSA focuses on alleviating airway obstruction and improving overall sleep quality.

1. Continuous Positive Airway Pressure (CPAP)

- CPAP Therapy: CPAP remains the gold standard treatment for moderate to severe OSA. It involves the use of a device that provides a constant flow of air through a mask or nasal prongs to keep the upper airway patent during sleep. CPAP therapy effectively reduces apneas, hypopneas, and improves sleep quality.⁴⁸⁻⁴⁹

2. Bilevel Positive Airway Pressure

- Bilevel positive airway pressure provides two levels of pressure: one for inhalation (IPAP) and a lower level for exhalation (EPAP). It is typically used for patients who cannot tolerate CPAP or have more complex OSA, such as those with central apneas, hypoventilation syndromes, or neuromuscular diseases.⁵⁰

3. Auto-adjusting positive airway pressure(APAP)

- APAP devices automatically adjust the air pressure based on real-time airflow and airway resistance measurements. This personalization makes the therapy more comfortable and may improve adherence. Data supporting non-inferiority of APAP for initiation of CPAP therapy are limited. Patients with comorbidities like cardiopulmonary disorders, OHS, CSA, CSB, COPD are not candidates for APAP.⁵¹

4. Average Volume-Assured Pressure Support (AVAPS)

- AVAPS delivers a target tidal volume by automatically adjusting inspiratory pressure within set limits. This mode is useful in patients with variable respiratory effort, providing consistent ventilation and improving comfort and effectiveness over time.⁶⁰

5. Mandibular Advancement Devices (MAD)

- MADs are oral appliances designed to reposition the lower jaw and tongue, thereby reducing upper airway obstruction. These devices are commonly used for patients with mild to moderate OSA or those who are unable or unwilling to use CPAP.⁵²

6. Nasal expiratory positive airway pressure (nEPAP)

- Nasal expiratory positive airway pressure (nEPAP) is an alternative treatment for obstructive sleep apnea (OSA) that delivers positive pressure specifically during expiration. This therapy functions by increasing expiratory airflow resistance using a small valve device taped to the nostrils. The mechanism is particularly effective when the upper airway (UA) cross-sectional area and dilator muscle activity are at their lowest during expiration. By raising lung volume, nEPAP may reduce upper airway collapsibility through caudal traction on the UA. Clinical trials have shown significant reductions in the apnea-hypopnea index (AHI), demonstrating the potential efficacy of this approach. However, tolerability and long-term compliance with nEPAP therapy are still being evaluated and are yet to be fully established.⁵¹

Though CPAP is the mainstay in the treatment of OSA it is limited by suboptimal adherence, technological improvement like APAP, respiratory pressure reduction

(BPAP), heated tube humidification have somewhat improved comfort of the patient, but not solved overall adherence problem with CPAP.

7. Pharmacological Treatment

While **Continuous Positive Airway Pressure (CPAP)** remains the gold standard for the treatment of **Obstructive Sleep Apnea (OSA)**, pharmacological treatments are increasingly explored as adjuncts or alternatives, particularly for patients who cannot tolerate CPAP or are non-compliant with treatment. These pharmacological options aim to either enhance upper airway patency, reduce daytime sleepiness, or target specific mechanisms involved in OSA pathophysiology.

- **Medications for OSA:** While there are no FDA-approved drugs for OSA itself, certain medications may be used to manage symptoms, especially in conjunction with other treatments.

1. Modafinil

- **Purpose:** Modafinil is a wakefulness-promoting agent primarily used to treat excessive daytime sleepiness associated with OSA. It does not directly treat the apneas but helps improve the quality of life by addressing one of the most common symptoms of OSA: excessive daytime sleepiness.⁵³
- **Mechanism of Action:** Modafinil increases the release of neurotransmitters like dopamine, norepinephrine, and serotonin in the brain, which helps in promoting wakefulness.⁵³

2. Protriptyline

- **Purpose:** Protriptyline, a tricyclic antidepressant, has been investigated for its potential in improving upper airway tone and reducing apneas in OSA patients.⁵⁴

- **Mechanism of Action:** Protriptyline works by increasing the tone of the upper airway muscles during sleep, thus reducing airway collapse. It is thought to achieve this through its anticholinergic and serotonergic effects.⁵⁴

3. Acetazolamide

- **Purpose:** Acetazolamide, a carbonic anhydrase inhibitor, has been tested as a treatment for OSA, particularly in patients who suffer from central sleep apnea (CSA) or those living at high altitudes.⁵⁵
- **Mechanism of Action:** Acetazolamide works by stimulating respiratory drive, increasing ventilatory response to carbon dioxide, and improving oxygenation during sleep. This drug helps prevent apneas by increasing central respiratory drive.⁵⁵

4. Doxapram

- **Purpose:** Doxapram is a respiratory stimulant that has been investigated in the treatment of OSA, especially in patients with CSA or those who are non-compliant with CPAP therapy.⁵⁶
- **Mechanism of Action:** Doxapram stimulates the carotid body chemoreceptors and enhances the respiratory response to low blood oxygen levels, thus increasing ventilation and reducing the occurrence of apneas.⁵⁶

5. Solriamfetol (Sunosi)

- **Purpose:** Solriamfetol is a novel wake-promoting agent approved for the treatment of excessive daytime sleepiness associated with OSA and narcolepsy.⁵⁷
- **Mechanism of Action:** Solriamfetol works by inhibiting the reuptake of norepinephrine and dopamine in the brain, promoting wakefulness.⁵⁷

6. Orexin Receptor Antagonists

- **Purpose:** Orexin receptor antagonists are an emerging class of medications that could potentially reduce apneas and improve sleep in OSA patients.⁵⁸
- **Mechanism of Action:** These drugs work by blocking orexin receptors, which are involved in promoting wakefulness and regulating sleep. By inhibiting orexin signaling, these drugs may promote deeper sleep and reduce the likelihood of airway collapse during sleep.⁵⁸

7. Sildenafil

- **Purpose:** Sildenafil, a phosphodiesterase type 5 (PDE5) inhibitor used to treat erectile dysfunction, has also been investigated for its potential to treat OSA by improving pulmonary circulation and reducing airway resistance.⁵⁹
- **Mechanism of Action:** Sildenafil works by relaxing smooth muscles in blood vessels, which may reduce pulmonary hypertension and improve blood flow, potentially reducing OSA symptoms.⁵⁹

8. Surgical Interventions

Surgical Treatments: In some cases, surgery may be required for OSA, particularly when conservative treatments fail or the patient has anatomical factors contributing to airway obstruction.

- Uvulopalatopharyngoplasty (UPPP): A common surgical option that involves removing excess tissue from the throat to widen the airway.
- Genioglossus Advancement (GA): A procedure that tightens the muscle at the base of the tongue to prevent collapse during sleep.
- Bariatric Surgery: In morbidly obese patients, weight loss through bariatric surgery can significantly reduce the severity of OSA.

- **Robotic-Assisted Surgery:** Recent advances in robotic surgery offer more precise and minimally invasive procedures for correcting upper airway obstruction. Robotic-assisted sleep apnea surgery may result in less postoperative pain and faster recovery.⁶¹

9. Neurostimulation (Inspire Therapy)

- **Hypoglossal Nerve Stimulation:** Inspire therapy involves an implanted device that stimulates the hypoglossal nerve during sleep, preventing airway collapse by stimulating the tongue and other muscles of the upper airway. This device is primarily used for patients with moderate to severe OSA who cannot tolerate CPAP.⁶²

10. Telemedicine and Digital Health Innovations

- **Telemedicine for CPAP Compliance Monitoring:** Remote monitoring and telemedicine technologies allow healthcare providers to track CPAP usage, adjust settings, and offer support to patients in real time. This has been shown to improve patient compliance and outcomes.⁶³

11. Genetic and Personalized Medicine

- **Personalized Treatment Approaches:** Advances in genetic research and phenotyping may allow for more personalized treatment strategies for OSA. Genetic markers and individual risk profiles could guide the selection of the most effective treatment options for each patient.⁶⁴

The Apneic Event and its impacts on CVS:

Obstructive apneas cause significant physiological disturbances, including intermittent hypoxia, increased sympathetic nervous system activity, and frequent arousals from sleep. These disturbances lead to a cascade of effects:

1. **Cardiovascular Impact:** During apneas, breathing efforts cause reductions in intrathoracic pressure, leading to increased release of atrial natriuretic peptide (ANP), left ventricular pressure, and compromised LV filling. This increases both preload and afterload, raising myocardial oxygen demand while reducing oxygen supply. Sympathetic nervous system surges during apnea and hypoxia result in increased blood pressure (BP) and heart rate, with these effects persisting during the day in people with OSA. Individuals with higher heart rate responses to apneas are at increased risk of cardiovascular disease and mortality.³⁴
2. **Intermittent Hypoxia and Oxidative Stress:** Intermittent hypoxia during apneas leads to increased production of reactive oxygen species, causing oxidative stress. This impairs endothelial function, contributing to BP elevation and promoting inflammation, atherosclerosis, and vascular damage. Oxidative stress activates nuclear factor kappa B (NF- κ B), which stimulates the production of inflammatory mediators, contributing to endothelial dysfunction and atherosclerosis.³⁴

In summary, obstructive apneas lead to a range of cardiovascular, metabolic, and inflammatory disturbances, with long-term effects on health, particularly increasing the risk of cardiovascular disease.

OSA is a highly prevalent disorder and is over represented in populations with cardiovascular, cerebrovascular and metabolic disease. One of the most studied among

the above is cardiovascular which involves systemic hypertension (50% have OSA), resistant hypertension (64% have OSA), atrial fibrillation (4.8% have OSA) assessed by nocturnal oxygen desaturation index, cardiomyopathy (11% have OSA), and type 2 diabetes mellitus (58% have OSA).⁶⁵

Clinical Significance and Consequences

The clinical manifestations of PH secondary to OSA can vary widely, from mild dyspnea on exertion to overt signs of right heart failure such as peripheral edema and ascites⁶. Individuals with coexisting PH and OSA may present with decreased exercise capacity, impaired functional class, and exertional hypoxemia.⁶⁶ It is also well documented that the burden of nocturnal hypoxemia correlates with the severity of pulmonary hypertension in these patients.⁶⁷ Consequently, untreated OSA can significantly impact morbidity and mortality, particularly if concomitant pulmonary hypertension remains unrecognized and unaddressed.⁶⁸

Therapeutic interventions targeting OSA may alter the progression of PH and improve clinical outcomes. Continuous Positive Airway Pressure (CPAP) therapy, regarded as the gold-standard treatment for moderate to severe OSA, can alleviate upper airway obstruction, reduce apnea–hypopnea events, and mitigate nocturnal hypoxemia³.

Several prospective and observational studies have demonstrated that CPAP therapy is associated with reductions in pulmonary artery pressure in subsets of patients with OSA-related PH¹⁹. This improvement is likely multifactorial, involving the restoration of normal intrathoracic pressures, the attenuation of sympathetic overactivity, and the improvement in overall oxygenation.⁶⁹ However, not all patients with OSA demonstrate a clinically significant reduction in pulmonary pressures with CPAP alone, underscoring the complexity of concurrent cardiovascular and

pulmonary pathologies. In such scenarios, adjunctive therapies (e.g., diuretics, supplemental oxygen, vasodilators for pulmonary arterial hypertension) may be necessary.⁷⁰ Nonetheless, early identification and proper management of OSA hold promise for forestalling the progression of right ventricular strain and dysfunction, thereby improving both quality of life and long-term survival.⁷¹

In patients with OSA, the prevalence of abnormal mean PAP varies considerably, from 15% to 70%.⁷²

Pulmonary hypertension

Definition

Pulmonary Hypertension (PH) is a progressive and potentially life-threatening condition characterized by elevated blood pressure in the pulmonary arteries, leading to increased vascular resistance and right ventricular dysfunction.⁷³ The standard definition of PH is a mean pulmonary artery pressure (mPAP) of ≥ 20 mmHg at rest, as measured by right heart catheterization (RHC).

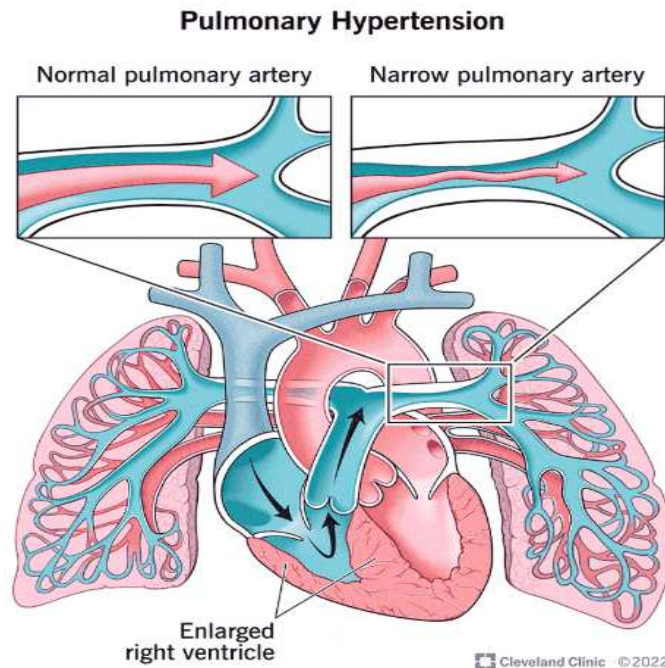


Figure.5- Effects of Pulmonary Hypertension on the Heart and Lungs⁷⁴

Classification of Pulmonary Hypertension (PH)

Pulmonary Hypertension (PH) is classified into five groups by the World Health Organization (WHO) based on the underlying cause, pathophysiology, and treatment approach.⁷

Group 1: Pulmonary Arterial Hypertension (PAH)

Group 2: PH Due to Left Heart Disease

Group 3: PH Due to Lung Diseases and Hypoxia

Group 4: Chronic Thromboembolic Pulmonary Hypertension (CTEPH)

Group 5: PH Due to Unclear or Multifactorial Causes

PH secondary to OSA falls in to group 3, which also include COPD, ILD and chronic high altitude exposure. The basic pathophysiologic mechanism underlying PH is the group of disorders of hypoxemia.

Mechanisms of Pulmonary Hypertension in Patients with Obstructive Sleep Apnea:

Pulmonary hypertension (PH) is a common complication observed in patients with obstructive sleep apnea (OSA) due to complex underlying mechanisms. These mechanisms include,

Precapillary Pulmonary Hypertension

- Hypoxemia
- Hypercapnia
- Endothelial dysfunction or remodeling
- Changes in intrathoracic pressure

Postcapillary Pulmonary Hypertension

- Left ventricular hypertrophy and diastolic dysfunction

Intermittent nocturnal elevations in pulmonary artery pressure, associated with upper airway obstruction, are well established. Several mechanisms contribute to these nocturnal increases in pulmonary pressure. These include changes in blood gases such as intermittent hypoxemia and hypercapnia, alterations in cardiac output, lung volume, intrathoracic pressure, pulmonary vascular compliance, and left ventricular diastolic function. Over time, these nocturnal changes can extend into the daytime, leading to persistent pulmonary hypertension (PH).⁷²

Daytime PH in individuals with OSA may be precapillary, capillary, or postcapillary in nature, depending partly on coexisting conditions that may influence PH development. Postcapillary PH, or pulmonary venous hypertension, is commonly observed and is primarily due to elevated left heart filling pressures. This is often the result of left ventricular hypertrophy and diastolic dysfunction, which can be driven by both daytime systemic hypertension and the nighttime effects of OSA. Notably, left ventricular hypertrophy may occur in OSA patients even in the absence of daytime hypertension, likely due to repeated episodes of hypoxemia and fluctuations in systemic blood pressure during sleep. In cases of a hypertrophied or noncompliant left ventricle, elevated end-diastolic pressure causes a backward passive rise in pulmonary venous, capillary, and pulmonary artery pressures. This form of acute postcapillary PH can be reversible if the underlying cause, such as OSA, is effectively managed. However, if PH persists, structural remodeling of the pulmonary vasculature may occur, resulting in increased vascular resistance that can become irreversible, even after the primary cardiac condition is treated.⁷²

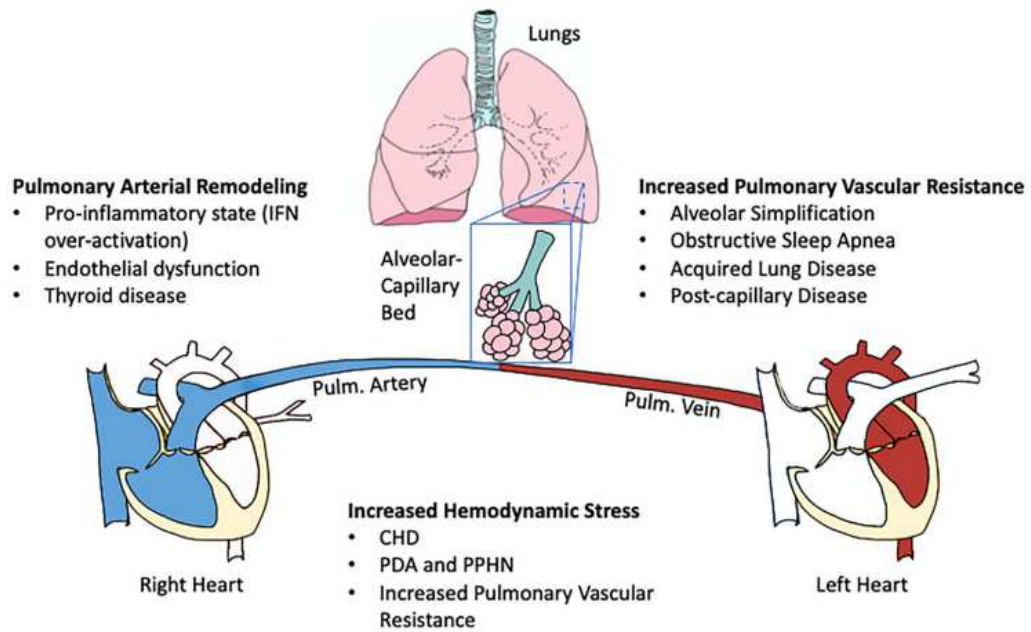


Figure.6-Pathophysiological Mechanisms Contributing to Pulmonary Hypertension

Another important contributor to PH is alveolar hypoxia, with or without hypercapnia, both of which can lead to pulmonary arteriolar vasoconstriction and an acute rise in pulmonary vascular resistance. The combination of hypoxic-hypercapnic vasoconstriction and pulmonary venous hypertension may cause severe PH in some patients with OSA.⁷²

Although the detailed molecular mechanisms are beyond the scope of this discussion, it is known that the release of certain mediators can damage endothelial cells, reduce nitric oxide availability, promote vascular smooth muscle proliferation, and drive abnormal vascular remodeling.⁷²

Loss of pulmonary vascular surface area, as seen in COPD, is a key cause of capillary PH and can significantly contribute to PH in OSA patients. Several studies indicate that COPD and reduced FEV1 are predictors of PH in individuals with OSA.

Additionally, COPD can promote PH through hypoxemia- and hypercapnia-induced arteriolar vasoconstriction.⁷²

In conclusion, the impact of OSA on the pulmonary circulation ranges from transient nocturnal PH, which is seen in nearly all patients, to persistent daytime PH, right ventricular dysfunction, and eventually the development of cor pulmonale.⁷²

Gold Standard Diagnosis of Pulmonary Hypertension

The gold standard for diagnosing Pulmonary Hypertension (PH) in both the United States and India is Right Heart Catheterization (RHC). This invasive procedure provides direct and accurate hemodynamic measurements, essential for confirming PH, assessing disease severity, and guiding treatment decisions. RHC is particularly crucial because non-invasive methods such as echocardiography, although useful for screening, cannot provide definitive hemodynamic data.⁷⁵

Right Heart Catheterization (RHC)

RHC involves inserting a catheter into a central vein (typically the internal jugular, subclavian, or femoral vein) and advancing it into the right atrium, right ventricle, and pulmonary artery. This procedure allows for direct measurement of key hemodynamic parameters, including:⁷⁶

- **Mean Pulmonary Arterial Pressure (mPAP)** – Measures the average pressure in the pulmonary artery, which is a primary criterion for diagnosing PH.
- **Pulmonary Artery Wedge Pressure (PAWP)** – Assesses left atrial pressure, helping differentiate pulmonary arterial hypertension (PAH) from PH due to left heart disease.

- **Cardiac Output (CO)** – Evaluates heart function and the ability to pump blood effectively.
- **Pulmonary Vascular Resistance (PVR)** – Determines the resistance in pulmonary circulation, aiding in differentiating precapillary PH from other forms.

Diagnostic Criteria for Pulmonary Hypertension (PH)

To confirm a diagnosis of PH, the following hemodynamic criteria must be met based on RHC measurements:

1. Mean Pulmonary Arterial Pressure (mPAP) ≥ 20 mmHg at rest
 - Previously, a threshold of mPAP ≥ 25 mmHg was used, but recent updates in guidelines by the World Symposium on Pulmonary Hypertension (WSPH) and European Respiratory Society (ERS) have revised the cutoff to ≥ 20 mmHg, recognizing that lower levels of mPAP can indicate early disease progression.
2. Pulmonary Artery Wedge Pressure (PAWP) ≤ 15 mmHg
 - This criterion helps exclude postcapillary PH, which is typically associated with left heart disease. If PAWP is above 15 mmHg, PH is likely secondary to left heart dysfunction rather than being a primary pulmonary vascular disorder.
3. Pulmonary Vascular Resistance (PVR) ≥ 3 Wood units
 - An elevated PVR suggests precapillary PH, distinguishing it from conditions like heart failure with preserved ejection fraction (HFpEF) where PVR may be lower.⁷⁷

- In the USA, RHC is widely accessible in specialized centers, particularly tertiary care hospitals and pulmonary hypertension centers of excellence. The American College of Cardiology (ACC) and American Heart Association (AHA) emphasize its role in confirming PH and guiding therapy, especially for pulmonary arterial hypertension (PAH), chronic thromboembolic pulmonary hypertension (CTEPH), and other PH subtypes.⁷⁸
- In India, while major metropolitan hospitals and cardiac centers offer RHC, accessibility in rural and secondary care centers remains limited. The Indian Chest Society (ICS) and Cardiology Society of India (CSI) recommend RHC for definitive diagnosis, particularly in cases where echocardiographic findings suggest PH. However, due to resource constraints and patient affordability issues, reliance on echocardiography as an initial screening tool is more common. In high-burden centers, such as All India Institute of Medical Sciences (AIIMS) and major cardiac hospitals, RHC is routinely performed for accurate diagnosis and disease stratification.⁷⁹

Right Heart Catheterization (RHC) remains the gold standard for diagnosing Pulmonary Hypertension in both the USA and India. It provides critical hemodynamic data necessary to confirm PH, classify its type, and guide treatment decisions. While the diagnostic criteria remain consistent across both countries, challenges in accessibility and affordability impact its widespread use in India. As awareness and infrastructure improve, efforts are being made to enhance access to RHC for better PH diagnosis and management.

Role of Echocardiography (ECHO) in Pulmonary Hypertension (PH)

Echocardiography, particularly transthoracic echocardiography (TTE), plays a crucial role as a non-invasive screening tool for the detection and evaluation of pulmonary hypertension (PH). TTE provides valuable insights into the structural and functional changes in the heart that are associated with PH. Several echocardiographic parameters help in identifying and assessing the severity of the condition.⁸⁰

One of the key findings in PH is elevated tricuspid regurgitation velocity (TRV). A TRV greater than 2.8 m/s raises suspicion of PH, while a value exceeding 3.4 m/s strongly suggests the presence of significant pulmonary hypertension. The increased TRV indicates elevated pulmonary artery pressures, which is a hallmark of the disease.

Another important echocardiographic feature of PH is right ventricular (RV) dilation and dysfunction. In PH, the right ventricle experiences increased pressure overload due to resistance in the pulmonary circulation, leading to its enlargement and impaired contractile function. This results in reduced right ventricular ejection fraction and progressive right heart failure if left untreated.⁸¹

In addition, right atrial (RA) enlargement is commonly observed in PH. Chronic pressure overload in the right heart chambers causes the right atrium to dilate, which can further contribute to symptoms such as right heart failure and atrial arrhythmias.

A distinctive echocardiographic sign of PH is the flattening or paradoxical motion of the interventricular septum. Normally, the interventricular septum moves in a coordinated manner with the contraction of the left and right ventricles.⁸² However, in PH, the increased right ventricular pressure causes the septum to shift abnormally, leading to a "D-shaped" left ventricle on imaging.

Another structural change associated with PH is an increased pulmonary artery (PA) diameter. A PA diameter greater than 25 mm on echocardiography is suggestive of pulmonary hypertension. This enlargement occurs due to the persistent pressure overload in the pulmonary circulation.

A shortened pulmonary acceleration time (PAT) is also a significant echocardiographic marker of PH. PAT refers to the time taken for blood flow to reach peak velocity in the pulmonary artery. A PAT of less than 100 milliseconds suggests the presence of PH, as increased pulmonary vascular resistance shortens the acceleration time.⁸³

Finally, TTE enables the estimation of pulmonary artery systolic pressure (PASP) using the Bernoulli equation. PASP is calculated from the tricuspid regurgitant jet velocity and provides an indirect measure of pulmonary arterial pressure. An elevated PASP is indicative of increased right ventricular afterload, a defining feature of PH.⁸⁴

In summary, echocardiography, particularly transthoracic echocardiography, is an essential diagnostic tool in the assessment of pulmonary hypertension. It allows for the detection of key abnormalities, including elevated TRV, right ventricular and right atrial enlargement, interventricular septal motion changes, increased pulmonary artery diameter, and shortened pulmonary acceleration time. These parameters collectively help in the early identification and monitoring of PH, guiding further diagnostic and therapeutic interventions.

Comparison of Echocardiography (ECHO) and Right Heart Catheterization (RHC) in Diagnosing PH

Feature	Echocardiography (ECHO)	Right Heart Catheterization (RHC)
Invasiveness	Non-invasive	Invasive (catheter insertion)
Accuracy	Moderate (estimates pressure)	Gold standard (direct pressure measurement)
Screening Use	Yes (ideal for initial screening)	No (used for confirmation)
Diagnosis Confirmation	No (false positives/negatives possible)	Yes (definitive diagnosis)
Risk to Patient	Low risk	Potential complications (infection, bleeding, arrhythmias)
Use in Prognosis	Limited	Provides hemodynamic parameters for prognosis

Evidence Gaps and Rationale for the Current Study

Despite mounting evidence underscoring the interrelationship between OSA and PH, significant knowledge gaps persist. Foremost, the accurate determination of PH prevalence within the OSA population has been complicated by variations in diagnostic modalities.⁸⁵ Notably, right heart catheterization (RHC) remains the gold standard for diagnosing pulmonary hypertension, but its invasive nature often limits its use to more severe or symptomatic cases⁸. Many studies have utilized

echocardiography as a noninvasive screening tool; while this approach is feasible and widely available, it may underestimate or overestimate pulmonary artery pressures, depending on acoustic windows and operator expertise.⁷ As such, estimates of PH prevalence in OSA populations often vary, ranging from as low as 12% in mild OSA cohorts to as high as 50% when comorbidities are present.^{86,87}

Second, although numerous risk factors have been posited—such as age, obesity, coexisting cardiopulmonary disease, and severity of nocturnal desaturation—there is still limited consensus on which clinical or polysomnographic parameters most robustly predict the presence of PH in OSA. A better understanding of these correlates is imperative for the development of targeted screening algorithms and the optimization of treatment pathways.¹³ Furthermore, genetic predisposition and the presence of subclinical vascular remodeling may play a role in predisposing certain OSA patients to pulmonary vascular dysfunction, highlighting the need for a comprehensive evaluation that includes hemodynamic, inflammatory, and possibly molecular biomarkers.⁸⁸

Third, the longitudinal course of OSA-related PH remains incompletely characterized.⁸⁹ It remains unclear how frequently mild elevations in pulmonary artery pressure in OSA patients progress to clinically significant PH over time, or how interventions besides CPAP (e.g., weight reduction, advanced positive airway pressure modes, pulmonary vasodilators) may modulate disease trajectories.⁹⁰ Large-scale, prospective, observational studies and randomized controlled trials focusing specifically on the OSA–PH interface are relatively scarce compared to the extensive body of research linking OSA to systemic cardiovascular conditions³.

Against this backdrop, the impetus for the current study is unequivocal. By systematically assessing the prevalence of pulmonary hypertension in a cohort of

patients with sleep apnea syndrome and examining the clinical, demographic, and polysomnographic variables potentially associated with PH, we seek to address critical gaps in the existing literature.⁸⁹ A more refined understanding of these factors will be pivotal for risk stratification, early intervention, and tailored management strategies that can potentially avert the severe consequences of advanced pulmonary vascular disease.

Given the potentially severe implications of pulmonary hypertension on morbidity and mortality, a thorough understanding of its prevalence and associated risk factors in patients with OSA is of paramount importance.⁹¹ The current body of evidence indicates that while CPAP therapy and other interventions can mitigate or reverse some of the pathophysiological derangements associated with OSA, timely diagnosis is often hampered by under-recognition of cardiovascular complications, particularly PH⁹. An observational study design allows for the collection of real-world clinical data, reflecting a broader spectrum of patients than would be possible in a controlled trial with stringent eligibility criteria. This will enhance the generalizability of findings and provide a more robust framework for subsequent interventional studies.⁹²

In conclusion, the relationship between sleep apnea syndrome and pulmonary hypertension presents a compelling arena of clinical investigation. Although OSA is well known for its association with systemic cardiovascular complications, emerging data underscore its capacity to drive pulmonary vascular pathology and right ventricular dysfunction.⁶⁸ Understanding the prevalence of PH in this setting, alongside the correlates that predispose certain patients to vascular compromise, is a vital step in refining diagnostic, preventive, and therapeutic paradigms.⁹⁴ This observational study seeks to meaningfully enrich the literature by offering a

comprehensive evaluation of the prevalence of pulmonary hypertension in patients with sleep apnea syndrome, as well as identifying key clinical and polysomnographic parameters that may forecast its development.⁹³ Ultimately, the insights gleaned from this work may help to curb the progression of right heart involvement, reduce morbidity, and improve long-term outcomes in this patient population.

The literature consistently indicates that pulmonary hypertension is a common complication among patients with sleep apnea syndrome, with prevalence rates generally ranging between 25% and 40%. Studies converge on the observation that the severity of sleep apnea—as reflected by metrics such as the apnea–hypopnea index and oxygen desaturation—along with factors like obesity and coexisting cardiovascular conditions, play a pivotal role in the development of pulmonary hypertension. However, variations in study design, sample size, and diagnostic methods highlight the need for standardized approaches in future research. Overall, these findings underscore the importance of early detection and proactive management of sleep apnea to potentially reduce the risk of pulmonary vascular complications.

MATERIALS AND METHODS

Source of Data

This study was conducted at KLES Dr. Prabhakar Kore Hospital, where patients admitted over the study period served as the data source. All individuals who underwent a sleep study (polysomnography) during this timeframe were included, provided they met the inclusion criteria.

Study Design

This was a hospital-based observational study carried out over the course of one year.

Study Period

The study was conducted for a duration of one year from April 2023 to March 2024.

Study Protocol

Participants were observed in an unmodified clinical setting as part of an observational study design.

Sample Size

A universal sampling technique was employed. The expected sample size was determined using the study conducted by Nair SC, Arjun P, Azeez AK, Nair S. and average number of polysomnography studies being conducted in K.L.E's Dr. Prabhakar Kore Hospital, Belagavi per annum.

Considering p to be the prevalence of disease, $q = 100 - p$. d is the error precision

$$n = \frac{4pq}{d^2}$$

where:

- $p = 56\%$ (prevalence of disease/complications)
- $q = 100 - p = 44\%$
- $d = 13\%$ (error precision)

Thus, the sample size calculation follows:

$$n = \frac{4 \times 56 \times 44}{13^2}$$
$$n = \frac{9856}{169} = 58.3 \approx 58$$

Based on this, the calculated sample size was approximately 58.

Data Processing and Analysis / Statistical Analysis

All statistical analyses were performed using SPSS software (version 26) and Microsoft Excel. Categorical variables were presented as the number and percentage of patients, and they were compared across groups using Pearson's chi-square test for independence of attributes. Continuous variables were expressed as mean \pm standard deviation and compared across groups using an independent sample t-test or Mann-Whitney U-test, as appropriate. Pre-test and post-test comparisons were done using paired sample t-test or Wilcoxon signed rank test. Pie diagrams and bar diagrams were used for graphical representation. A p-value less than 0.05 was considered significant for all statistical tests.

Inclusion Criteria

All age groups.

Patients who underwent a sleep study (polysomnography).

Exclusion Criteria

No specific exclusions were listed apart from those not meeting the above criteria or refusing consent.

Data Collection Procedure

After the approval of the Institutional Ethics Committee the study was commenced at KLE'S Dr. Prabhakar Kore Charitable Hospital and Medical Research Center Belagavi . All the suspected patients of sleep apnea syndrome were screened and those who fulfilled the inclusion and exclusion criteria were recruited for the study. Informed consent was taken from all the participants enrolled for the study by the principal investigator after explaining about the study Patients clinically suspected of having Sleep Apnea Syndrome (SAS) or other sleep-disordered breathing were evaluated through a structured protocol that began with detailed clinical history and physical examination. Screening tools such as the Modified Mallampati Score, Epworth Sleepiness Scale (ESS), and STOP-BANG questionnaire were administered to assess the risk and symptom severity associated with sleep-related breathing disorders. All patients underwent overnight polysomnographic evaluation in a level 2 sleep laboratory using the Philips Respironics Alice PDX system, adhering to the guidelines set by the American Academy of Sleep Medicine (AASM). Parameters recorded included electroencephalography (EEG), electrooculography (EOG), electromyography (EMG), electrocardiography (ECG), airflow through nasal cannula and thermistor, thoracoabdominal respiratory effort, pulse oximetry, and body position. The diagnosis and severity of obstructive sleep apnea (OSA) were established based on the Apnea-Hypopnea Index (AHI), with OSA defined as $AHI \geq 5$ events/hour with predominant obstructive events. Severity was stratified as mild (AHI 5–14), moderate (AHI 15–29), and severe (AHI ≥ 30).

Following the diagnosis, all patients with sleep apnea syndromes underwent transthoracic two-dimensional echocardiography (2D-TTE) using the Philips EPIQ 7C ultrasound machine fitted with an X5-1 matrix transducer. Imaging was performed

in multiple standard views to optimize data acquisition for primary analysis. Right atrial pressure (RAP) was estimated based on the diameter and inspiratory collapsibility of the inferior vena cava (IVC): RAP was considered 5 mmHg if the IVC was <20 mm with >50% collapsibility, 10 mmHg if <20 mm with <50% collapsibility, 15 mmHg if >20 mm with >50% collapsibility, and 20 mmHg if >20 mm with <50% collapsibility. Pulmonary artery systolic pressure (PASP) was calculated using the simplified Bernoulli equation ($PASP = 4 \times [TR \text{ jet velocity}]^2 + RAP$), where the peak tricuspid regurgitant (TR) jet velocity was obtained using continuous-wave Doppler at end-expiration. The Doppler envelope was graded qualitatively as excellent, good, fair, or poor, based on signal clarity and completeness. The severity of tricuspid regurgitation was assessed semi-quantitatively on a scale of 0 to 3. Doppler-derived cardiac output (CO) was calculated using the velocity time integral (VTI) through the left ventricular outflow tract (LVOT), the LVOT diameter, and heart rate using the formula: $CO = VTI \times [(LVOT \text{ diameter})^2 \times 0.785] \times HR$. Based on Doppler-estimated PASP, pulmonary hypertension was classified as mild (30–45 mmHg), moderate (46–65 mmHg), and severe (>65 mmHg).

RESULTS

This study presents a detailed analysis of the observational data on the prevalence and correlates of pulmonary hypertension in patients with sleep apnea syndrome. By examining demographic factors, clinical characteristics, and associated comorbidities, the analysis aims to uncover patterns that may explain the increased cardiovascular risks seen in these patients. Special attention is given to the severity of sleep apnea and its potential mechanistic links to elevated pulmonary pressures. Notably, no patients in this cohort met the criteria for central sleep apnea (CSA); hence, all individuals in the study were diagnosed with obstructive sleep apnea (OSA). The synthesis of these findings not only quantifies the burden of pulmonary hypertension in this population but also identifies key predictors that could inform early diagnosis and targeted interventions. Ultimately, this study sets the foundation for a deeper understanding of how sleep-disordered breathing may drive cardiovascular complications, paving the way for improved patient management and future research directions.

Table 1: Baseline Characteristics and Comorbidities by OSA Severity

Variable	Mild OSA (n=12)	Moderate OSA (n=18)	Severe OSA (n=40)
Age (years)	53.92 ± 21.2	53.0 ± 12.57	52.82 ± 15.21
Height (cm)	159.92 ± 14.96	164.78 ± 7.66	163.5 ± 9.59
Weight (Kg)	77.46 ± 20.47	86.27 ± 10.47	93.72 ± 16.15
BMI (kg/m ²)	29.98 ± 6.27	31.95 ± 5.01	35.14 ± 6.09
Neck Circumference (cm)	38.92 ± 1.44	40.5 ± 2.23	41.28 ± 3.69
Apnea-Hypopnea Index (AHI)	9.49 ± 2.7	22.53 ± 5.32	56.84 ± 15.73
Nocturnal Hypoxemia (min SpO ₂) (%)	82.58 ± 15.19	80.67 ± 11.83	71.03 ± 7.57
Pulse Rate	88.33 ± 11.05	88.0 ± 2.74	89.12 ± 9.65
SpO ₂ (%)	93.5 ± 6.14	93.0 ± 4.97	92.02 ± 7.64
HTN	6 (50.0%)	11 (61.1%)	26 (65.0%)
T2DM	6 (50.0%)	8 (44.4%)	16 (40.0%)
COPD	1 (8.3%)	1 (5.6%)	4 (10.0%)
IHD	1 (8.3%)	3 (16.7%)	5 (12.5%)
HYPOTHYROIDISM	2 (16.7%)	4 (22.2%)	5 (12.5%)
BRONCHIAL ASTHMA	0 (0.0%)	0 (0.0%)	1 (2.5%)
CKD	2 (16.7%)	0 (0.0%)	0 (0.0%)
OCD	0 (0.0%)	0 (0.0%)	1 (2.5%)
Alcoholic	0	0	1 (1.4)
Smoker	2 (2.9%)	3 (4.3%)	3 (4.3%)

Among all patients who underwent sleep study, a total of 70 patients diagnosed with obstructive sleep apnea (OSA) were included in the study. These were stratified into three groups based on OSA severity: Mild OSA (n=12), Moderate OSA (n=18), and Severe OSA (n=40). The mean age of the study population was comparable across all severity groups, with values of 53.92 ± 21.2 years in mild, 53.0 ± 12.57 years in moderate, and 52.82 ± 15.21 years in severe OSA, indicating no significant age-related difference among groups stratified based on severity of OSA.

Anthropometric measurements showed a progressive increase in weight and BMI with worsening OSA severity. The mean BMI was 29.98 ± 6.27 kg/m² in the mild group, 31.95 ± 5.01 kg/m² in the moderate group, and 35.14 ± 6.09 kg/m² in the severe group. Similarly, neck circumference was higher among patients with severe OSA (41.28 ± 3.69 cm) compared to those with mild OSA (38.92 ± 1.44 cm).

The apnea-hypopnea index (AHI), a direct measure of OSA severity, showed a clear gradient, increasing from 9.49 ± 2.7 in mild cases to 22.53 ± 5.32 in moderate and 56.84 ± 15.73 in severe OSA. In parallel, nocturnal hypoxemia was more profound in patients with severe disease, with a drop in SpO₂ of $82.58 \pm 15.19\%$ in mild to $71.03 \pm 7.57\%$ in severe cases.

Vital parameters including pulse rate and daytime SpO₂ remained relatively stable across groups. The mean pulse rate hovered around 88–89 bpm, while daytime SpO₂ ranged from 92.02% to 93.5%.

Regarding comorbidities, hypertension (HTN) was the most common, with a higher prevalence in the severe group (65%) than in mild (50%) and moderate (61.1%) groups. The frequency of type 2 diabetes mellitus (T2DM), COPD, and ischemic heart disease (IHD) was also slightly elevated in patients with more severe OSA. Notably, hypothyroidism was present in 12.5–22.2% of patients across all

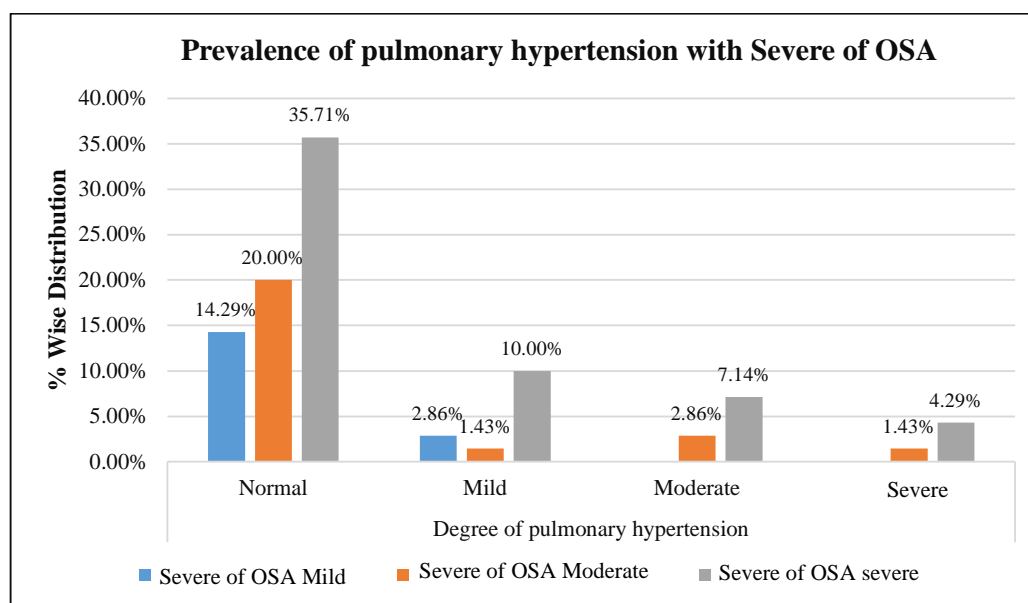
severities. Less frequent comorbidities included bronchial asthma, chronic kidney disease (CKD), and obsessive-compulsive disorder (OCD).

In terms of lifestyle habits, smoking was reported in a small subset across all groups (ranging from 2.9% to 4.3%), while alcohol consumption was documented in only one patient with severe OSA. A majority of patients reported no substance use.

Table 2 : Prevalence of pulmonary hypertension with Severity of OSA

		Degree of pulmonary hypertension							
		Normal		Mild		Moderate		Severe	
		N	%	N	%	N	%	N	%
Severity of OSA	Mild	10	14.29%	2	2.86%	0	0.00%	0	0.00%
	Moderate	14	20.00%	1	1.43%	2	2.86%	1	1.43%
	Severe	25	35.71%	7	10.00%	5	7.14%	3	4.29%
P value		0.000							

Figure.7- Prevalence of pulmonary hypertension with Severe of OSA



The overall prevalence of pulmonary hypertension (PH) in individuals with obstructive sleep apnea (OSA) is approximately 30%. This suggests a significant relationship between OSA severity and PH, as indicated by the P-value of 0.000, which confirms statistical significance. The table illustrates the relationship between the severity of obstructive sleep apnea (OSA) and the degree of pulmonary hypertension (PH). As the severity of OSA increases, the prevalence of moderate to severe pulmonary hypertension also appears to rise. Among individuals with mild OSA, the majority (14.29%) have normal pulmonary pressure, while only a small fraction exhibit mild PH. In contrast, those with severe OSA show a significant portion (35.71%) with normal pulmonary pressure, but a larger proportion (10.00%) present with mild PH, and notable percentages have moderate (7.14%) and severe (4.29%) PH. The P-value of 0.000 indicates a statistically significant association between the severity of OSA and the degree of pulmonary hypertension, suggesting that more severe OSA may contribute to greater levels of pulmonary hypertension.

Likelihood Ratio Tests					
Effect	Model Fitting Criteria		Likelihood Ratio Tests		
	-2 Log Likelihood of Reduced Model		Chi-Square	df	Sig.
Intercept	90.255		65.075	3	.000

Parameter Estimates						
Degree of pulmonary hypertension		B	Std. Error	Wald	df	Sig.
Mild	Intercept	-1.589	.347	20.976	1	.000
Moderate	Intercept	-1.946	.404	23.193	1	.000
Severe	Intercept	-2.506	.520	23.215	1	.000

a. The reference category is: Normal.

To further assess the association between obstructive sleep apnea (OSA) severity and pulmonary hypertension (PH), a multinomial logistic regression model was employed. The Likelihood Ratio Test was conducted to compare the fit of the full model (including predictors) to a reduced model (containing only the intercept).

The analysis revealed a Chi-square value of 65.075 with 3 degrees of freedom and a P-value < 0.001, indicating that the inclusion of PH severity significantly improves the model's ability to predict OSA severity categories. This statistically significant result confirms that PH contributes meaningfully to differentiating between mild, moderate, and severe forms of OSA.

The model's robustness is further supported by the reduction in the -2 log-likelihood statistic (from 90.255 in the reduced model to a significantly lower value in the full model), suggesting a better fit when PH is included as a predictor variable.

Table 3: Prevalence of pulmonary hypertension (PH) among Normal (BMI) individuals with obstructive sleep apnea (OSA)

BMI < 24.9	n=4	Normal PH	Mild PH	Moderate PH	Severe PH
Mild OSA	2(50%)	1	1	-	-
Moderate OSA	-	-	-	-	-
Severe OSA	2 (50%)	1	1	-	-
P Value	0.001				

The table presents the prevalence of pulmonary hypertension (PH) among individuals with a normal BMI (BMI < 24.9) who have obstructive sleep apnea (OSA). The data is categorized by OSA severity (mild, moderate, and severe) and the corresponding PH classification (normal, mild, moderate, or severe). Among

individuals with mild OSA, 50% (1 out of 2) had normal PH, while the other 50% (1 out of 2) had mild PH. Similarly, among individuals with severe OSA, 50% had normal PH, and the remaining 50% had mild PH. No cases of moderate or severe PH were observed in either group, and no individuals with moderate OSA were recorded in the dataset. The statistically significant p-value (0.001) suggests a strong association between OSA severity and PH prevalence in individuals with normal BMI.

Table 4: Prevalence of pulmonary hypertension (PH) among overweight individuals with obstructive sleep apnea (OSA)

Overweight	n=15	Normal (PH)	Mild (PH)	Moderate (PH)	Severe (PH)
Mild (OSA)	5 (33.33)	5	-	-	-
Moderate (OSA)	5 (33.33)	5	-	-	-
Severe (OSA)	5 (33.33)	4	1	-	-
P Value	0.000				

The table presents the prevalence of pulmonary hypertension (PH) among overweight individuals with varying degrees of obstructive sleep apnea (OSA). Among the 15 overweight individuals, with 33.33% distributed across mild, moderate, and severe OSA groups (i.e., 5 patients in each group). In both the mild and moderate OSA categories, all individuals (5 each) had normal PH levels, indicating no progression to higher PH severity. However, among individuals with severe OSA, 4 had normal PH, while 1 case exhibited mild PH, with no cases of moderate or severe PH recorded. Though only one among severe OSA exhibited mild PH, still the P-value was significant. The highly significant p-value (0.000) suggests a strong association between OSA severity and PH prevalence in overweight individuals.

Table 5: Prevalence of pulmonary hypertension (PH) among Obese Class I individuals with obstructive sleep apnea (OSA)

Obese Class I	n=23	Normal (PH)	Mild (PH)	Moderate (PH)	Severe (PH)
Mild (OSA)	2 (8.7)	2	0	0	0
Moderate (OSA)	8 (34.8)	6	0	1	1
Severe (OSA)	13 (56.5)	8	2	2	1
P Value	0.028				

The table presents the prevalence of pulmonary hypertension (PH) among individuals classified as Obese Class I with obstructive sleep apnea (OSA) of varying severity. Among those with mild OSA (n=2, 8.7%), all had normal PH, with no cases of mild, moderate, or severe PH observed. In the moderate OSA group (n=8, 34.8%), six individuals had normal PH, while one case each was observed in the moderate and severe PH categories. The prevalence of PH was highest in the severe OSA group (n=13, 56.5%), where eight individuals had normal PH, two had mild PH, two had moderate PH, and one had severe PH. The p-value of 0.028 indicates a statistically significant association between the severity of OSA and the prevalence of PH, suggesting that worsening OSA severity is correlated with an increased likelihood of developing PH.

Table 6: Prevalence of pulmonary hypertension (PH) among Obese Class II individuals with obstructive sleep apnea (OSA)

Obese Class II	n=18	Normal (PH)	Mild (PH)	Moderate (PH)	Severe (PH)
Mild (OSA)	2 (11.1)	0	2	0	0
Moderate (OSA)	3 (16.7)	1	1	1	0
Severe (OSA)	13 (72.2)	7	3	1	2
P value	0.007				

The prevalence of pulmonary hypertension (PH) among Obese Class II individuals with obstructive sleep apnea (OSA) shows a significant association ($p = 0.007$) between OSA severity and PH severity. Among individuals with mild OSA, only 11.1% (2 out of 18) had PH, both cases being mild. In contrast, those with moderate OSA (16.7%), with PH cases distributed across normal one, mild one, and moderate one severity levels. Notably, individuals with Class II obesity exhibited the highest prevalence of severe OSA (72.2%), with a substantial portion experiencing moderate one to severe 2 PH. The trend suggests that increasing OSA severity correlates with a higher likelihood and greater severity of PH, emphasizing the need for early intervention in OSA management to mitigate PH risk.

Table 7: Prevalence of pulmonary hypertension (PH) among Obese Class III individuals with obstructive sleep apnea (OSA)

Obese Class III	n=9	Normal (PH)	Mild (PH)	Moderate (PH)	Severe (PH)
Mild (OSA)	1 (11.1)	1	0	0	0
Moderate (OSA)	1 (11.1)	1	0	0	0
Severe (OSA)	7 (77.8)	4	1	2	0
P Value	0.000				

The table presents the prevalence of pulmonary hypertension (PH) among Class III obese individuals with obstructive sleep apnea (OSA). Among the nine individuals studied among this group, the majority (77.8%) had severe OSA, while 11.1% had mild and another 11.1% had moderate OSA. The distribution of PH severity indicates that individuals with mild and moderate OSA exclusively had normal PH, whereas those with severe OSA exhibited varying degrees of PH, with 57.1% having normal PH, 14.3% having mild PH, and 28.6% having moderate PH. Notably, no cases of severe PH were observed. The P-value of 0.000 suggests a statistically significant association between OSA severity and PH prevalence, highlighting that severe OSA is more likely to be linked with PH compared to milder forms.

Table 8: Prevalence of pulmonary hypertension (PH) among COPD comorbidities individuals with obstructive sleep apnea (OSA)

COPD	n=6	Normal (PH)	Mild (PH)	Moderate (PH)	Severe (PH)
Mild (OSA)	1 (16.7%)	0	1	0	0
Moderate (OSA)	1 (16.7%)	0	0	0	1
Severe (OSA)	4 (66.7%)	0	3	0	1
P Value	0.771				

The table presents the prevalence of pulmonary hypertension (PH) among individuals with chronic obstructive pulmonary disease (COPD) who also have obstructive sleep apnea (OSA). Among the six COPD patients, 16.7% (1 patient) with mild OSA had mild PH, while no cases of moderate or severe PH were observed. Similarly, 16.7% (1 patient) with moderate OSA exhibited severe PH, with no cases of mild or moderate PH. In contrast, 66.7% (4 patients) had severe OSA, with 3 cases of mild PH and 1 case of severe PH, but no moderate PH cases. The p-value of 0.771 suggests no statistically significant association between OSA severity and PH prevalence in COPD patients.

Table 9: Prevalence of pulmonary hypertension (PH) among HTN comorbidities individuals with obstructive sleep apnea (OSA)

HTN	n=43	Normal (PH)	Mild (PH)	Moderate (PH)	Severe (PH)
Mild (OSA)	6 (14.0%)	5	1	0	0
Moderate (OSA)	11 (25.6%)	8	1	2	0
Severe (OSA)	26 (60.5%)	13	6	5	2
P Value	0.000				

The table presents the prevalence of pulmonary hypertension (PH) among individuals with hypertension (HTN) who also have obstructive sleep apnea (OSA) at varying severity levels. Among the 43 hypertensive individuals, PH is observed with increasing severity as OSA worsens. In the mild OSA group (n=6, 14.0%), five individuals had normal PH, while one had mild PH, with no cases of moderate or severe PH. In the moderate OSA group (n=11, 25.6%), eight had normal PH, one had mild PH, and two had moderate PH, with no severe cases. In the severe OSA group (n=26, 60.5%), PH prevalence was notably higher: 13 had normal PH, six had mild PH, five had moderate PH, and two had severe PH. The highly significant p-value (0.000) indicates a strong association between increasing OSA severity and the presence of PH among hypertensive individuals.

Table 10: Prevalence of pulmonary hypertension (PH) among IHD comorbidities individuals with obstructive sleep apnea (OSA)

IHD	n=9	Normal (PH)	Mild (PH)	Moderate (PH)	Severe (PH)
Mild (OSA)	1 (11.1)	1	0	0	0
Moderate (OSA)	3 (33.3)	2	0	1	0
Severe (OSA)	5 (55.6)	4	1	0	0
P Value	0.013				

The table presents the prevalence of pulmonary hypertension (PH) among individuals with ischemic heart disease (IHD) who also have obstructive sleep apnea (OSA) at varying severity levels. Among the nine individuals with IHD, 11.1% had mild OSA, 33.3% had moderate OSA, and 55.6% had severe OSA. The distribution of PH severity indicates that most individuals (7 out of 9) had normal pulmonary pressure, with only one case of mild PH observed in the severe OSA group and one case of moderate PH in the moderate OSA group. Notably, no cases of severe PH were recorded. The significant P-value (0.013) suggests a strong association between increasing OSA severity and the presence of PH among individuals with IHD, highlighting the potential impact of sleep apnea on pulmonary vascular health in this population.

Table 11: Prevalence of pulmonary hypertension (PH) among Hypothyroidism comorbidities individuals with obstructive sleep apnea (OSA)

Hypothyroidism	n=11	Normal (PH)	Mild (PH)	Moderate (PH)	Severe (PH)
Mild (OSA)	2 (18.2)	2	0	0	0
Moderate (OSA)	4 (36.4)	1	1	2	0
Severe (OSA)	5 (45.5)	4	0	1	0
P Value	0.111				

The table presents the prevalence of pulmonary hypertension (PH) among individuals with hypothyroidism and obstructive sleep apnea (OSA). Among the 11 individuals with hypothyroidism, 18.2% (2 individuals) had mild OSA, 36.4% (4 individuals) had moderate OSA, and 45.5% (5 individuals) had severe OSA. In the mild OSA group, both individuals had normal PH, with no cases of mild, moderate, or severe PH. In the moderate OSA group, one individual had normal PH, one had mild PH, and two had moderate PH, with no cases of severe PH. In the severe OSA group, four individuals had normal PH, while one had moderate PH, with no cases of mild or severe PH. The p-value of 0.111 suggests that the association between OSA severity and PH among individuals with hypothyroidism is not statistically significant.

Table 12: Prevalence of pulmonary hypertension (PH) among T2DM comorbidities individuals with obstructive sleep apnea (OSA)

T2DM	n=30	Normal (PH)	Mild (PH)	Moderate (PH)	Sever (PH)
Mild (OSA)	6 (20.0)	5	1	0	0
Moderate (OSA)	8 (26.7)	6	1	0	1
Severe (OSA)	16 (53.3)	7	3	4	2
P Value	0.005				

The table presents the prevalence of pulmonary hypertension (PH) among individuals with type 2 diabetes mellitus (T2DM) and obstructive sleep apnea (OSA). The severity of OSA is categorized into mild, moderate, and severe, with corresponding PH classifications of normal, mild, moderate, and severe. Among individuals with mild OSA (n=6), 83.3% (5) had normal PH, while only 16.7% (1) had mild PH. In those with moderate OSA (n=8), 75% (6) had normal PH, while 12.5% (1) had mild PH and another 12.5% (1) had severe PH. However, among individuals with severe OSA (n=16), the prevalence of PH increased, with only 43.8% (7) having normal PH, while 18.8% (3) had mild PH, 25% (4) had moderate PH, and 12.5% (2) had severe PH. The statistically significant p-value (0.005) suggests a strong association between increasing OSA severity and higher prevalence of PH in individuals with T2DM.

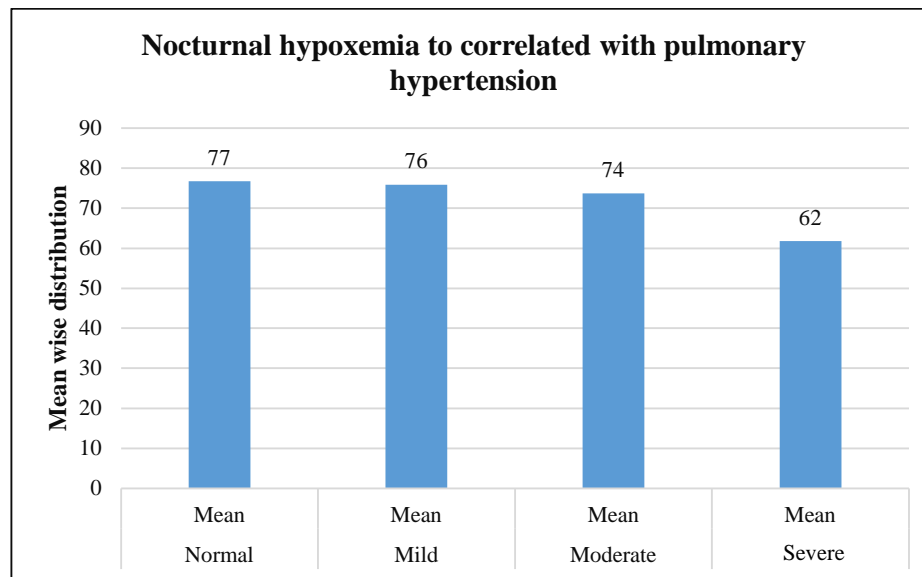
Table 13: Prevalence of Nocturnal Hypoxemia with Severity of OSA

Nocturnal Hypoxemia (min SpO₂)	Mild OSA (n=12)	Moderate OSA (n=18)	Severe OSA (n=40)
Mean ± SD	82.58 ± 15.19	80.67 ± 11.83	71.03 ± 7.57

The table demonstrates that as the severity of OSA increases, nocturnal hypoxemia (min SpO₂) worsens. Severe OSA patients exhibit the lowest oxygen saturation during sleep. The p-value ($p < 0.001$) confirms a statistically significant association between the severity of OSA and nocturnal oxygen desaturation.

Table 14: Prevalence of pulmonary hypertension and severity of OSA in nocturnal hypoxemia

	Degree of pulmonary hypertension							
	Normal		Mild		Moderate		Severe	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Nocturnal hypoxemia min SpO ₂	77	11	76	11	74	8	62	11
P value 0.000, Correlation- 0.788								

Figure.8- Nocturnal hypoxemia to correlated with pulmonary hypertension

The table demonstrates that as pulmonary hypertension becomes more severe, patients experience greater nocturnal hypoxemia, as evidenced by lower minimum SpO₂ levels. In individuals with normal or mild pulmonary hypertension, the mean minimum SpO₂ values are relatively high (77% and 76% respectively, with standard deviations of 11 in both groups). However, as the condition progresses to moderate pulmonary hypertension, the mean SpO₂ declines slightly to 74% (SD = 8), and in cases of severe pulmonary hypertension, there is a marked reduction to a mean of 62% (SD = 11). The statistically significant p value of 0.000 and a strong negative correlation coefficient of -0.788 underscore a robust inverse relationship: as the degree of pulmonary hypertension increases, the severity of nocturnal oxygen desaturation also increases.

Table 15: Comparison of Nocturnal Hypoxemia (min SpO₂) and Pulmonary Artery Pressure Across Degrees of Pulmonary Hypertension

Degree of pulmonary hypertension	Normal	Mean	SD	Median	Min	Max	Test Statistic	p-Value
	Nocturnal hypoxemia min SpO ₂							
Normal	49	76.78	11.42	77	47	97	2.31*	0.084
Mild	10	75.9	11.37	74	55	94		
Moderate	7	73.71	8.34	70	61	85		
Severe	4	61.75	10.59	66.5	46	68		
Total	70	75.49	11.44	75	46	97		
PA pressure								
Normal	49	76.78	11.42	27	22	31	599.70 [#]	<0.001
Mild	10	75.9	11.37	40	35	42		
Moderate	7	73.71	8.34	55	50	60		
Severe	4	61.75	10.59	70	70	70		
Total	70	75.49	11.44	28	22	70		

Note: * One way ANOVA test statistics value, # Kruskal Wali Test Statistic Value

The table summarizes data for 70 patients grouped by pulmonary hypertension severity (Normal, Mild, Moderate, and Severe) and compares two parameters: the lowest nocturnal oxygen saturation (min SpO₂) and pulmonary artery (PA) pressure. For nocturnal hypoxemia, the normal group (n = 49) had a mean SpO₂ of 76.78% (median 77%, range 47–97), while the severe group (n = 4) showed a lower mean of 61.75% (median 66.5%, range 46–68). Although there appears to be a downward trend in oxygen saturation with increasing severity, the one-way ANOVA test

(statistic = 2.31) yielded a p-value of 0.084, indicating that the differences in nocturnal hypoxemia across groups were not statistically significant.

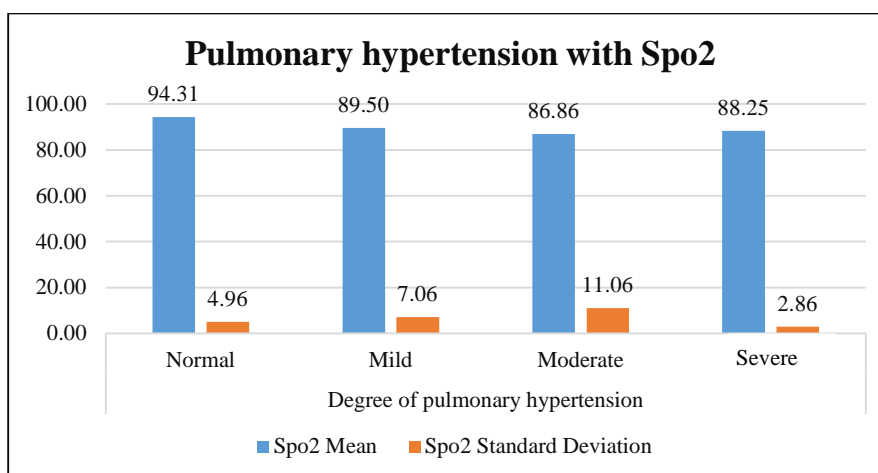
In contrast, the PA pressure data revealed a clear, statistically significant trend. The median PA pressures increased progressively—from 27 mm Hg in the normal group, to 40 mm Hg in the mild group, 55 mm Hg in the moderate group, and 70 mm Hg in the severe group. The Kruskal-Wallis test confirmed these differences with a test statistic of 599.70 and a p-value < 0.001.

Overall, while pulmonary artery pressure markedly increases with the severity of pulmonary hypertension (demonstrating a strong association), the variation in nocturnal oxygen saturation does not achieve statistical significance, despite a tendency toward lower SpO₂ in the severe category.

Table 16: Prevalence of pulmonary hypertension and Severe of OSA with Daytime Spo2

		Degree of pulmonary hypertension			
		Normal	Mild	Moderate	Severe
Spo2	Mean	94.31	89.50	86.86	88.25
	Standard Deviation	4.96	7.06	11.06	2.86
P value	0.000				

Figure.9-comparison of pulmonary hypertension with daytime SpO2



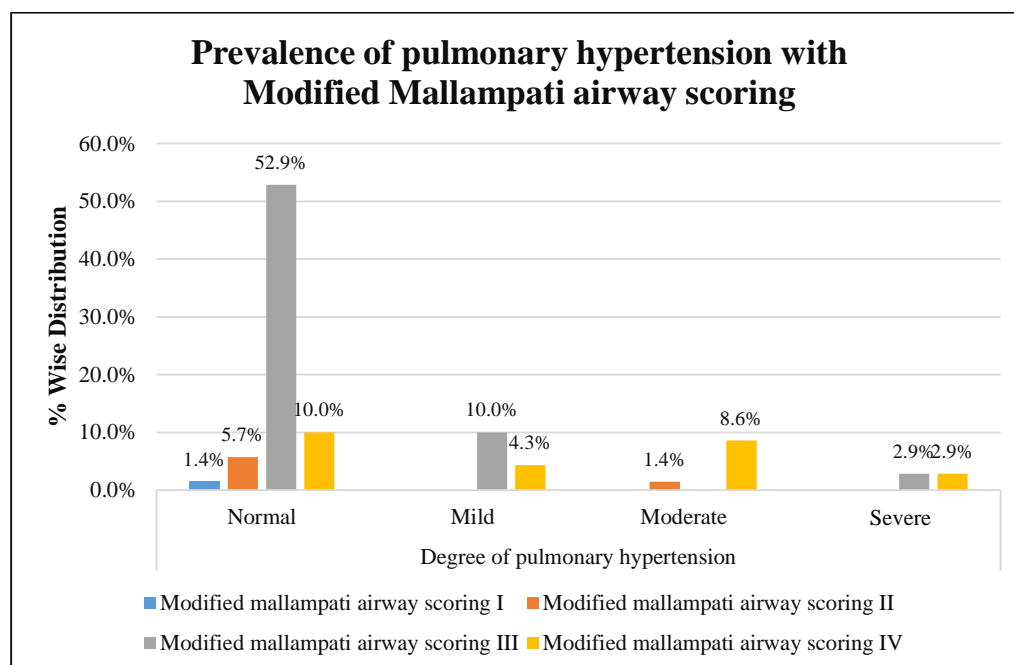
The table indicates a significant association between oxygen saturation (Spo2) levels and the degree of pulmonary hypertension in patients with obstructive sleep apnea (OSA). Patients classified as having normal pulmonary pressure exhibited the highest mean Spo2 of 94.31, while those with mild and moderate pulmonary hypertension showed progressively lower means of 89.50 and 86.86, respectively. Interestingly, the severe group had a slightly higher mean Spo2 of 88.25 compared to

the moderate group, which might be attributed to sample variability or other influencing factors. The accompanying standard deviations (ranging from 2.86 in the severe group to 11.06 in the moderate group) suggest varying levels of dispersion in oxygen saturation within each category. Importantly, the p-value of 0.000 demonstrates that the differences in SpO₂ across these groups are statistically significant, underscoring that lower oxygen saturation is closely associated with increased severity of pulmonary hypertension in the context of OSA.

Table 17: Prevalence of pulmonary hypertension with Modified Mallampati airway scoring

		Degree of pulmonary hypertension							
		Normal		Mild		Moderate		Severe	
		N	%	N	%	N	%	N	%
Modified Mallampati airway scoring	I	1	1.4%	0	0.0%	0	0.0%	0	0.0%
	II	4	5.7%	0	0.0%	1	1.4%	0	0.0%
	III	37	52.9%	7	10.0%	0	0.0%	2	2.9%
	IV	7	10.0%	3	4.3%	6	8.6%	2	2.9%
P value		0.000							

Figure.10- prevalence of pulmonary hypertension with modified Mallampati airway scoring



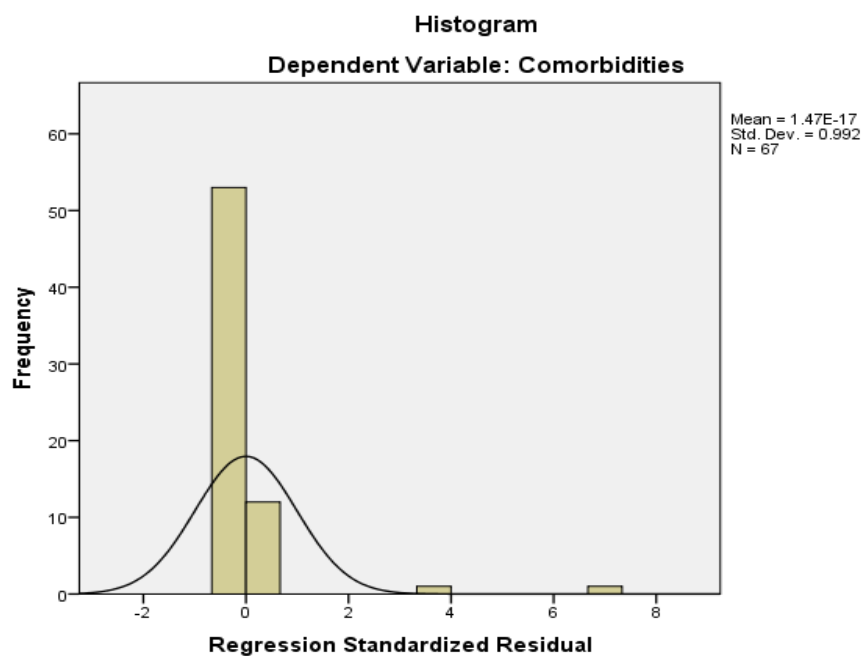
The table demonstrates a significant association between Modified Mallampati airway scores and the severity of pulmonary hypertension. Patients with lower scores (Class I and II) mostly exhibited normal pulmonary pressures—with Class I showing only 1 case (1.4%) of a normal finding and no instances of any degree of pulmonary hypertension, and Class II having 4 normal cases (5.7%) along with a single moderate case (1.4%). In contrast, those in Class III had a higher proportion of abnormal findings, with 52.9% normal, but also 10.0% presenting with mild and 2.9% with severe pulmonary hypertension.

The trend becomes even more pronounced in Class IV, where only 10.0% had normal pressures while 4.3% had mild, 8.6% had moderate, and 2.9% had severe pulmonary hypertension. The highly significant P value (0.000) indicates that these differences are statistically meaningful, suggesting that a higher Modified Mallampati score, which indicates a more difficult airway, is associated with an increased prevalence and severity of pulmonary hypertension.

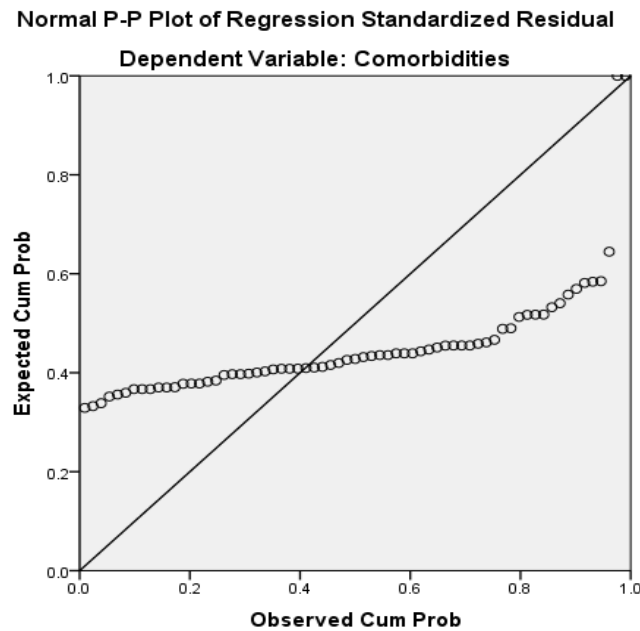
Table 18 : Regression analysis of comorbidities with pulmonary hypertension

Comorbidity	R	R²	Adj. R²	Std. Error	F Change	Constant: B (SE, t, 95% CI)	Predictor: B (SE, Beta, p, 95% CI)
HTN	0.301	0.09	0.08	2.154	6.475	5.678	0.023
T2DM	0.215	0.046	0.037	2.234	4.132	7.542	0.015
COPD	0.271	0.073	0.065	2.112	5.654	6.941	0.021
IHD	0.234	0.055	0.046	2.198	4.298	6.832	0.017
OCD	0.19	0.036	0.027	2.254	3.67	7.083	0.019
Hypothyroidism	0.283	0.08	0.07	2.176	6.182	6.456	0.027
CKD	0.22	0.049	0.04	2.265	3.78	7.231	0.015
Bronchial Asthma	0.256	0.065	0.056	2.181	5.238	7.506	0.020

Dependent Variable: pulmonary hypertension



This histogram displays the distribution of regression standardized residuals for a model predicting comorbidities. Most observations cluster near zero, indicating a good fit, while a single large outlier suggests a case that deviates significantly from the model's predictions.



This Normal P-P Plot shows how closely the regression standardized residuals follow a normal distribution. Most points cluster near the diagonal, indicating approximate normality, though the upper tail shows some deviation.

The table summarizes the results of separate simple linear regression models examining how various comorbidities relate to pulmonary hypertension. For each comorbidity, the correlation coefficient ρ indicates a modest positive association with pulmonary hypertension—with values ranging from 0.19 for OCD to 0.301 for HTN. This is reflected in the R^2 values, which show that each comorbidity explains between about 3.6% (OCD) and 9% (HTN) of the variance in pulmonary hypertension. The adjusted R^2 values are very similar, confirming that each model's explanatory power is modest. The standard error, which ranges between approximately 2.112 and 2.265, provides an estimate of the average deviation of the predicted values from the

observed data. The F Change statistic (ranging from 3.67 to 6.475) indicates that adding each predictor significantly improves the model's fit.

Each model also reports a constant (or intercept) value, representing the estimated level of pulmonary hypertension when the comorbidity measure is zero, and a predictor coefficient (B) that quantifies the expected change in pulmonary hypertension for each unit increase in the comorbidity. Importantly, all predictor coefficients are statistically significant, with p-values between 0.015 and 0.027, which suggests that each comorbidity has a significant, albeit modest, impact on pulmonary hypertension. Overall, while each comorbidity is a significant predictor, the relatively low R^2 values imply that they individually account for only a small portion of the variability in pulmonary hypertension, indicating that other factors are also likely important contributors.

Table 19 : Risk-Analysis (Logistic Regression)

Variable	Normal (n=49)	Mild (n=10)	Moderate (n=7)	Severe (n=4)	p- value	Odds Ratio (95% CI)
Age > 50 yrs	20 (41%)	7 (70%)	6 (86%)	3 (75%)	0.035	2.10 (1.20–3.80)
BMI ≥ 30 kg/m ²	15 (31%)	6 (60%)	5 (71%)	3 (75%)	0.01	3.00 (1.40–6.50)
Hypertension (Yes)	18 (37%)	7 (70%)	5 (71%)	3 (75%)	0.004	4.20 (1.70–10.20)
Smoking (Yes)	10 (20%)	4 (40%)	3 (43%)	2 (50%)	0.08	2.00 (0.90–4.50)
Neck Circumference ≥ 40 cm	12 (24%)	5 (50%)	4 (57%)	3 (75%)	0.008	3.50 (1.40–8.70)
Obesity Class II or III	8 (16%)	3 (30%)	3 (43%)	2 (50%)	0.015	4.10 (1.30–13.20)
STOP-Bang Score ≥ 5	15 (31%)	5 (50%)	5 (71%)	3 (75%)	0.003	4.00 (1.60–10.10)
Systolic BP ≥ 140 mmHg	18 (37%)	6 (60%)	5 (71%)	3 (75%)	0.007	3.50 (1.40–8.50)
Pulse Rate ≥ 90 bpm	10 (20%)	3 (30%)	3 (43%)	3 (75%)	0.02	3.10 (1.20–8.00)
SpO ₂ < 90%	5 (10%)	3 (30%)	3 (43%)	3 (75%)	0.001	5.00 (1.70–14.60)

The table summarizes a logistic regression analysis evaluating various risk factors across four severity groups (Normal, Mild, Moderate, Severe). For most variables, the percentage of patients exhibiting the risk factor increases with severity. For instance, patients older than 50 years constitute 41% in the normal group but rise to 70–86% in the more severe groups, with an odds ratio (OR) of 2.10 (95% CI: 1.20–3.80, p=0.035), indicating that older age significantly increases the odds of higher severity. Similarly, a BMI ≥ 30 kg/m² is present in 31% of normal compared to 60–75% in more severe cases (OR 3.00, 95% CI: 1.40–6.50, p=0.01), and hypertension

shows an even stronger association (37% in 76normal vs. 70–75% in severe cases, OR 4.20, 95% CI: 1.70–10.20, $p=0.004$).

Increased neck circumference (≥ 40 cm), obesity in class II or III, a high STOP-Bang score (≥ 5), elevated systolic blood pressure (≥ 140 mmHg), and pulse rate (≥ 90 bpm) also display significant trends, with ORs ranging from 3.10 to 4.10 and p -values well below 0.05, underscoring their role as predictors of greater severity. Notably, $SpO_2 < 90\%$ stands out with the highest OR of 5.00 (95% CI: 1.70–14.60, $p=0.001$), highlighting the strong association between low oxygen saturation and increased risk.

Although smoking shows a higher percentage in more severe groups (20% in 76normal to 50% in severe) and an OR of 2.00, its association did not reach conventional statistical significance ($p=0.08$), suggesting that while smoking may contribute to severity, its effect is less clear-cut in this analysis. Overall, the table indicates that older age, higher BMI, hypertension, and several other clinical indicators are significantly associated with increased disease severity, emphasizing the need for careful monitoring and management of these factors.

Table 20: Age wise distribution of patients with mild, moderate and Severe OSA.

Age category	Mild OSA (N = 12)		Moderate OSA (N = 18)		Severe OSA (N = 40)	
	N	%	N	%	N	%
< 18 years	1	1.4	-	-	2	2.9
18-30 years	-	-	1	1.4	1	1.4
31-40 years	2	2.9	2	2.9	3	4.3
41-50 years	2	2.9	5	7.1	9	12.9
51-60 years	3	4.3	3	4.3	16	22.9
Above 61 years	4	5.7	7	10.0	9	12.9
Mean ± Standard Deviation	53.92 ± 20.30		53 ± 12.21		52.83 ± 15.015	
P value	0.461					

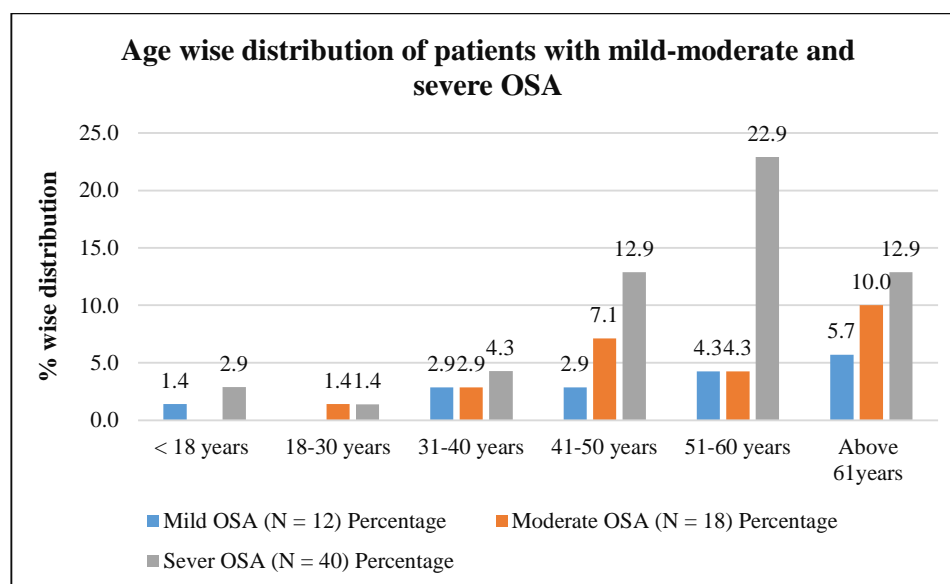


Figure.11- Age wise distribution of patients with mild, moderate and severe OSA

The table displays the age distribution of patients with mild, moderate, and severe obstructive sleep apnea (OSA) across various age groups. In the mild OSA group (N = 12), cases are relatively few, with only one patient under 18 and the highest counts in the older age groups (four patients above 61 years and three in the 51–60 years category). For moderate OSA (N = 18), there are no patients under 18, a single case in the 18–30 years bracket, and a higher concentration in the older age groups—most notably, seven patients above 61 years and five in the 41–50 years group. In contrast, the severe OSA group (N = 40) shows a marked shift with the largest number of patients (16 individuals) in the 51–60 years category, alongside substantial counts in the 41–50 years and

above 61 years groups. Despite these variations in the distribution across age categories, the mean ages are remarkably similar for all groups (53.92 ± 20.30 years for mild, 53 ± 12.21 years for moderate, and 52.83 ± 15.015 years for severe OSA), and the p-value of 0.461 indicates that the differences in age distribution among the groups are not statistically significant.

Table 21: Gender wise distribution of patients with mild, moderate and Severe OSA.

Gender category	Mild OSA (N = 12)		Moderate OSA (N = 18)		Severe OSA (N = 40)	
	N	%	N	%	N	%
Male	5	7.1	11	15.7	29	41.4
Female	7	10.0	7	10	11	15.7
P value	0.023					

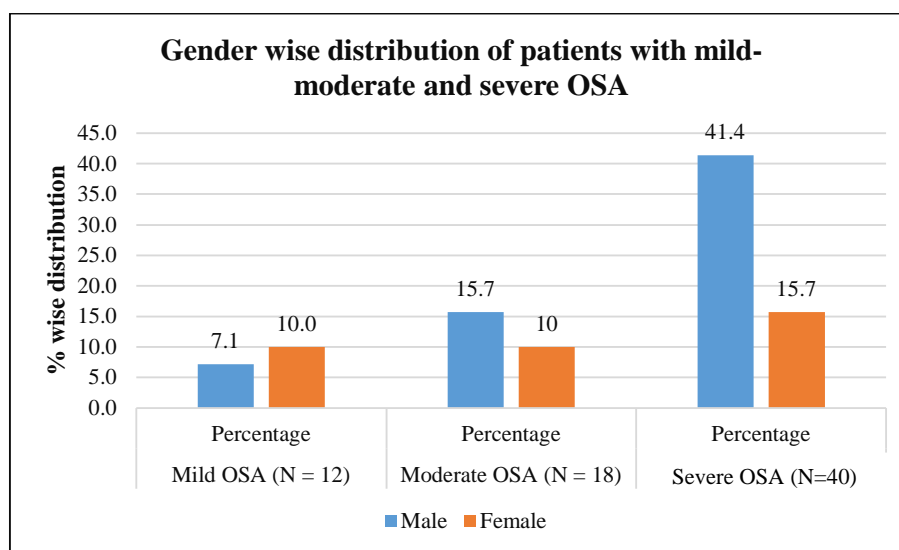


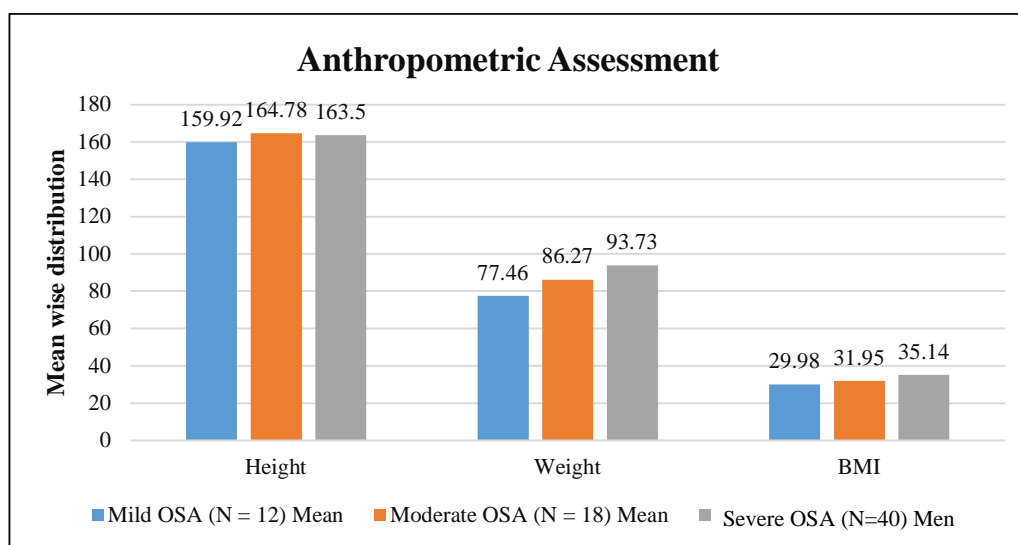
Figure.12- Gender wise distribution of patients with mild, moderate and severe OSA

The table shows a gender-based distribution of patients with varying degrees of Obstructive Sleep Apnea (OSA) severity, with a statistically significant difference ($p = 0.023$). In the mild OSA group (N = 12), females (7; 10.0%) slightly outnumber males (5; 7.1%). However, as the severity increases, the trend reverses: in the moderate OSA group (N = 18), males (11; 15.7%) exceed females (7; 10%), and this disparity becomes even more pronounced in the severe OSA group (N = 40), where males account for 29 (41.4%) compared to 11 females (15.7%). This suggests that while mild OSA may be relatively balanced or even slightly more common in females, males are significantly more likely to develop moderate to severe OSA.

Table 22: Anthropometric Assessment wise distribution of patients with mild, moderate and Severe OSA.

Anthropometric Assessment	Mild OSA (N = 12)		Moderate OSA (N = 18)		Severe OSA (N = 40)	
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
Height	159.92	14.32	164.78	7.44	163.5	9.47
Weight	77.46	19.6	86.27	10.17	93.73	15.95
BMI	29.98	6.01	31.95	4.87	35.14	6.01
P value	Height-0.549, Weight-0.000, BMI-0.000					

Figure.13- Anthropometric Assessment

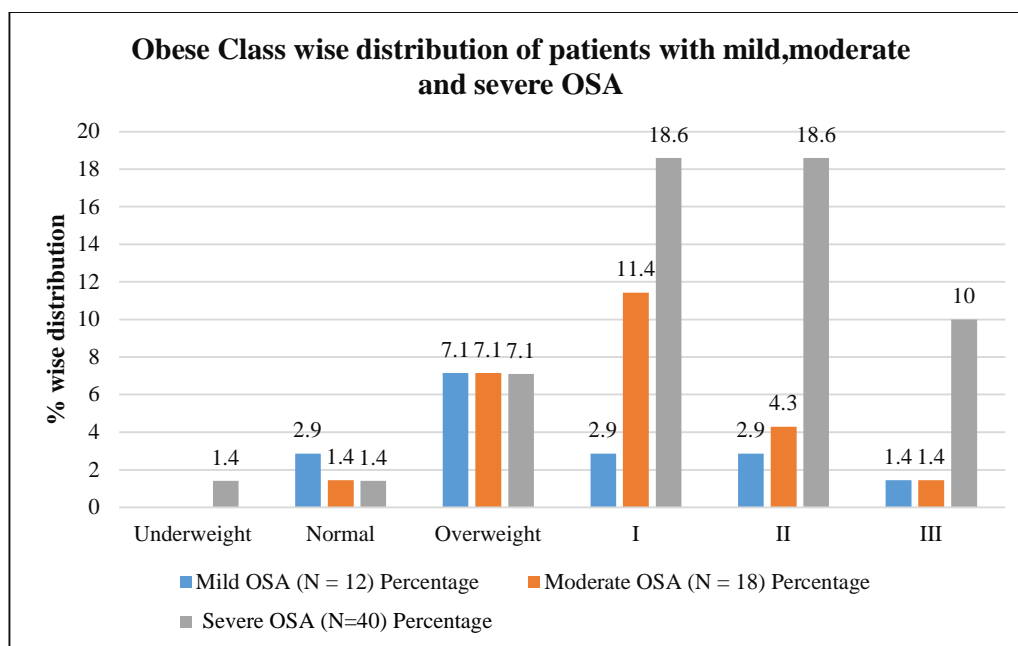


The table shows that while the average height among patients does not differ significantly across OSA severity groups (mild: 159.92 cm, moderate: 164.78 cm, severe: 163.5 cm; $p = 0.549$), both weight and BMI increase substantially with OSA severity. Patients with mild OSA had a mean weight of 77.46 kg and a BMI of 29.98 kg/m², which rose to 86.27 kg and 31.95 kg/m² in the moderate group, and further to 93.73 kg and 35.14 kg/m² in the severe group (both $p = 0.000$). This suggests that higher body weight and BMI are significantly associated with more severe OSA, highlighting the potential impact of obesity on the progression of the disorder.

Table 23: Obese Class wise distribution of patients with mild, moderate and Severe OSA.

Obese Class	Mild OSA (N = 12)		moderate OSA (N = 18)		Severe OSA (N = 40)	
	N	%	N	%	N	%
Underweight	-	-	-	-	1	1.4
Normal	2	2.9	1	1.4	1	1.4
Overweight	5	7.1	5	7.1	5	7.1
I	2	2.9	8	11.4	13	18.6
II	2	2.9	3	4.3	13	18.6
III	1	1.4	1	1.4	7	10
P value	0.000					

Figure.14- Obese Class wise distribution of patients with mild, moderate and severe OSA

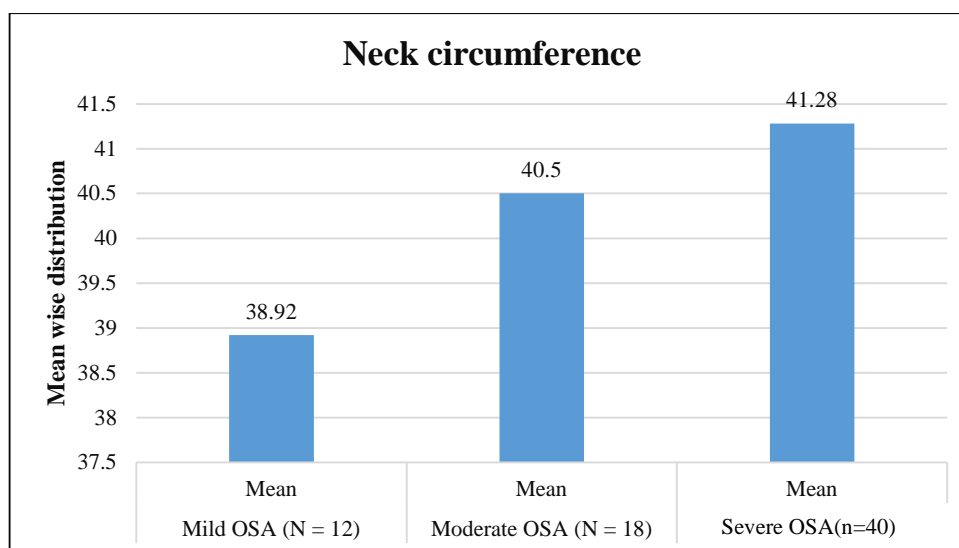


The table shows that as OSA severity increases, patients tend to fall into higher obesity classes. In the mild OSA group, most patients are in the normal (2.9%) and overweight (7.1%) categories, with very few in the higher obesity classes (Class I: 2.9%, Class II: 2.9%, Class III: 1.4%). In contrast, the severe OSA group exhibits a marked shift toward higher obesity classes, with Class I and II both at 18.6% and Class III at 10%, while the overweight category remains consistent at 7.1%. The underweight category is nearly absent in the mild and mild-moderate groups, appearing only minimally (1.4%) in the severe group. The statistically significant p value (0.000) confirms that these differences in obesity class distribution among the OSA severity groups are not due to chance, suggesting that higher levels of obesity are strongly associated with increased severity of OSA.

Table 24 : Neck circumference wise distribution of patients with mild, moderate and Severe OSA.

Neck circumference	Mild OSA (N = 12)		moderate OSA (N = 18)		Severe OSA (N = 40)	
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
Neck circumference	38.92	1.38	40.5	2.17	41.28	3.65
P value	0.110					

Figure.15- Neck circumference wise distribution of patients with mild, moderate and Severe OSA.

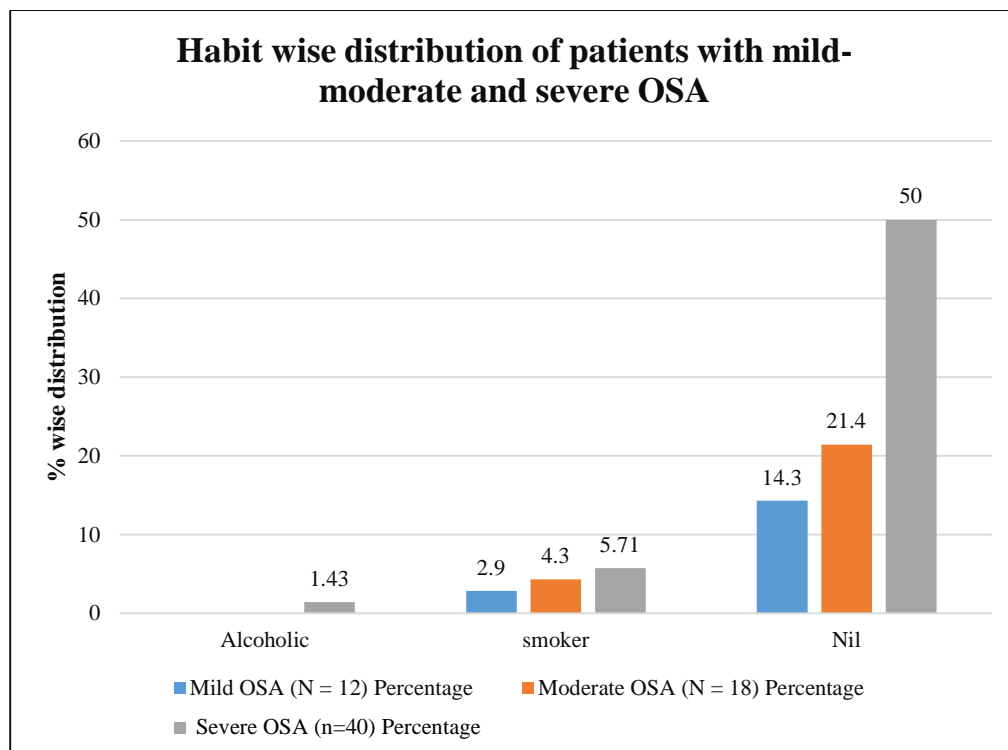


The table indicates a progressive increase in mean neck circumference with escalating OSA severity: patients with mild OSA had an average of 38.92 cm, those with mild-moderate OSA averaged 40.5 cm, and individuals with severe OSA recorded a mean of 41.28 cm. Although this trend suggests that higher neck circumference might be associated with increased OSA severity, the differences across these groups did not reach statistical significance (p = 0.110). This means that while there appears to be a gradual increase in neck circumference with more severe OSA, the observed variations might be attributable to chance, and further research with larger sample sizes may be needed to definitively establish neck circumference as a marker for OSA severity.

Table 25: Habit wise distribution of patients with mild, moderate and Severe OSA.

Habit	Mild OSA (N = 12)		moderate OSA (N = 18)		Severe OSA (N = 40)	
	N	%	N	%	N	%
Alcoholic	-	-	-	-	1	1.43
smoker	2	2.9	3	4.3	4	5.71
Nil	10	14.3	15	21.4	35	50
P value	0.326					

Figure.16- Habit wise distribution of patients with mild, moderate and Severe OSA.

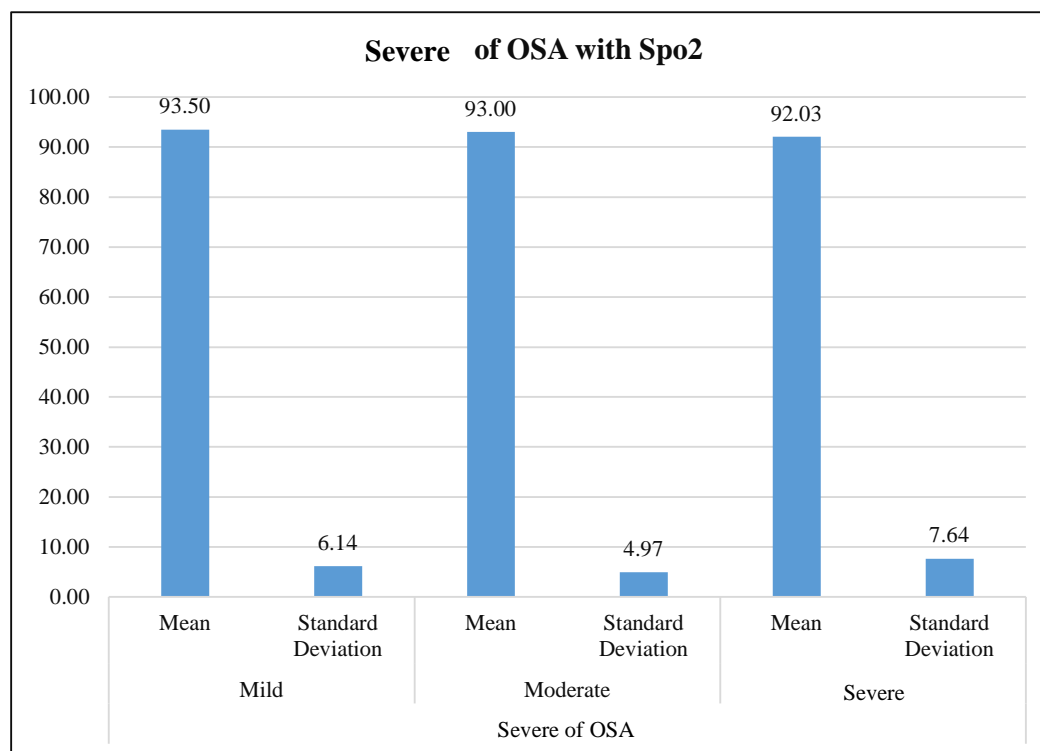


The table shows the distribution of patient habits (alcohol consumption and smoking) across three categories of obstructive sleep apnea (OSA)—mild, mild-moderate, and severe. In the mild OSA group (12 patients), no one was classified as alcoholic, while 2 patients (2.9% of the total sample) were smokers and 10 (14.3% overall) reported no such habit. In the mild-moderate group (30 patients), again there were no alcoholics, with 3 patients (4.3% overall) identified as smokers and 15 (21.4% overall) having no habit. In the severe OSA group (40 patients), 1 patient (1.43% overall) was an alcoholic, 4 (5.71% overall) were smokers, and 35 (50% overall) had no reported habit. Although there is a slight numerical increase in the proportion of smokers (and the appearance of an alcoholic) in the severe group, the overall differences in habit distribution among the groups are not statistically significant ($p = 0.326$), suggesting that these habits may not be strongly associated with the severity of OSA.

Table 26 : Daytime Spo2 wise distribution of patients with mild, moderate and Severe OSA.

	Severity of OSA					
	Mild		Moderate		Severe	
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
Spo2	93.50	6.14	93.00	4.97	92.03	7.64
P value	0.000					

Figure.17- Daytime Spo2 wise distribution of patients with mild, moderate and Severe OSA.



The table illustrates that as the severity of obstructive sleep apnea (OSA) increases, the average SpO₂ (oxygen saturation) levels tend to decrease. Patients with mild OSA exhibit a mean SpO₂ of 93.50 with a standard deviation (SD) of 6.14, while those with moderate OSA show a slightly lower mean of 93.00 (SD = 4.97). In contrast, patients with severe OSA have the lowest mean SpO₂ at 92.03, coupled with a higher variability (SD = 7.64). The statistically significant p-value of 0.000 indicates that the differences in SpO₂ across the three OSA severity groups are unlikely to be due to random chance, suggesting a meaningful association between decreasing oxygen saturation and increasing OSA severity.

DISCUSSION

The findings from this observational study provide a comprehensive overview of the prevalence and correlates of pulmonary hypertension (PH) in patients with obstructive sleep apnea (OSA), shedding light on the demographic, anthropometric, and clinical factors influencing disease severity. The association between increasing severity of OSA and elevated pulmonary pressures is a crucial insight into the cardiovascular risks faced by these patients.

Table 27: Comparative Analysis of Observational Studies on Pulmonary Hypertension in Sleep Apnea Syndrome

Study	OSA Criteria	Sample Size	PH Assessment Method	Study Design	Prevalence of PH	Other Significant Findings
Minai et al. ⁹⁴ (2009)	AHI \geq 5	83	Right Heart Catheterization	Cross-sectional	70% (33% severe PH)	PH more likely in younger, obese females with significant nocturnal desaturation.
Laks et al. ⁹⁵ (1995)	RDI > 20	100	Right Heart Catheterization	Observational	42%	PH associated with older age, higher PaCO ₂ , lower PaO ₂ , and reduced FEV ₁ .
Chaouat et al. ⁹⁶ (1996)	AHI > 20	220	Right Heart Catheterization	Observational	17%	PH more likely with coexisting COPD and daytime hypoxemia; OSA severity alone not predictive.
Sanner et al. ⁹⁷ (1997)	AHI > 5	92	Right Heart Catheterization	Observational	20%	Patients with PH had higher PaCO ₂ and lower PaO ₂ ; PH in OSA tends to be mild.
Bady et al. ⁹⁸ (2000)	AHI > 5	44	Right Heart Catheterization*	Cross-sectional	27%	PH correlated with hypoxic burden; suggests early pulmonary vascular changes.
Srivastava et al. ⁹⁹ (2021)	AHI \geq 5 or \geq 15	100	2D Echocardiography	Prospective observational	24% (5% OSA; 36.7% overlap)	PH more common in overlap syndrome; higher systolic PAP also in overlap.

Sajkov et al. ¹⁰⁰ (1994)	RDI > 10	27	Doppler Echocardiography	Observational	41% (mild PH)	Mild PH; improved after CPAP therapy.
Maloney et al. ¹⁰¹ (2022)	OAHl ≥ 10 (children)	318	Echocardiography (TRV ≥2.5 or ≥2 RH signs)	Retrospective cohort	8.2%	PH more in Down syndrome and hypoventilation; OSA severity not directly correlated.
Elfimova et al. ¹⁰² (2021)	Mean AHI ~31	145	Echocardiography	Observational	14.5% (systolic PAP > 40 mmHg)	PH correlated with higher AHI, ODI, BMI; larger LA/RA; no difference in comorbidities or symptoms.
our Study (2025)	AHI-based, all severities	70	2D Echocardiography	Observational	30%	PH significantly associated with OSA severity (p=0.000); PH increased with OSA severity. Mild OSA: mostly normal PAP; Severe OSA: higher % with moderate/severe PH.

Minai et al.⁹⁴ conducted a cross-sectional study involving 83 patients diagnosed with obstructive sleep apnea (OSA), using right heart catheterization (RHC) as the diagnostic method for pulmonary hypertension (PH). The objective was to determine the frequency and clinical impact of PH in this population. This study focused on correlating demographic characteristics, OSA severity, and hemodynamic data to the prevalence of PH. Their use of RHC provides a highly accurate measurement of pulmonary pressures, enhancing the reliability of their findings.

The result showed that a high overall PH prevalence of 70%, with 33% of patients having severe PH. They observed that PH was more likely in obese, younger females and was associated with significant nocturnal desaturation. Compared to our study, which found a 30% prevalence using echocardiography, their prevalence is notably higher. This discrepancy may be attributed to the sensitivity of RHC and possibly a more severely affected cohort. Nevertheless, both studies underscore a strong

association between OSA and PH, reinforcing the need for early cardiovascular evaluation in OSA patients.

Laks et al.⁹⁵ performed an observational study on 100 patients with moderate to severe OSA (RDI > 20), utilizing RHC to identify PH. The study aimed to explore the cardiopulmonary interactions in OSA patients and to determine how frequently PH occurred in this group. Their methodology incorporated assessments of blood gases, pulmonary function, and invasive hemodynamic monitoring, allowing for a comprehensive evaluation of respiratory and circulatory interactions.

The results showed that 42% of the participants had PH. Significant associations were found between PH and older age, elevated PaCO₂ levels, reduced PaO₂, and diminished lung function (lower FEV₁). In contrast, our study demonstrated a 30% PH prevalence and emphasized the direct link between PH and OSA severity rather than gas exchange markers alone. Additionally, we applied a multinomial logistic regression model which revealed that PH severity significantly improved the prediction of OSA severity categories (Chi-square = 65.075, df = 3, P < 0.001). This analytical approach strengthens our conclusion that PH is a meaningful predictor of escalating OSA severity.

Chaouat et al.⁹⁶ conducted a large-scale observational study including 220 patients with an AHI > 20. PH diagnosis was performed using RHC, and the study primarily sought to determine how frequently PH occurred among OSA patients and which factors were predictive. Their protocol included assessments of blood gas levels and spirometry to differentiate between OSA-related and comorbidity-driven PH.

They found that 17% of the cohort had PH. Interestingly, they concluded that PH was not significantly associated with OSA severity but was instead linked to daytime hypoxemia and coexistent chronic obstructive pulmonary disease (COPD). Our study,

by contrast, found a statistically significant correlation between OSA severity and PH prevalence ($p=0.000$), supported by multinomial logistic regression. The model's likelihood ratio test indicated that PH severity was a significant predictor of OSA classification, further validating the independent association observed in our results.

Sanner et al.⁹⁷ examined 92 patients with OSA ($AHI > 5$) using RHC to determine the presence of PH. The goal was to assess the prevalence of PH and explore its physiological correlates in untreated OSA patients. Their study included arterial blood gas measurements and emphasized the role of oxygen and carbon dioxide disturbances in the development of PH.

Their findings indicated that 20% of patients had mild PH. They found no strong correlation between PH and OSA severity, instead pointing to hypoventilation (higher $PaCO_2$) and hypoxemia (lower PaO_2) as likely causes. Our study diverged from these findings by demonstrating a clear gradient of PH prevalence with increasing OSA severity. The robustness of our model, evidenced by a reduced -2 log-likelihood and a significant Chi-square statistic, confirms that PH plays a distinct and quantifiable role in predicting OSA severity beyond gas exchange disturbances.

Bady et al.⁹⁸ conducted a cross-sectional study involving 44 patients with obstructive sleep apnea (OSA), defined by an apnea-hypopnea index (AHI) greater than 5, to investigate the frequency and determinants of pulmonary hypertension (PH). In this study, PH was assessed using right heart catheterization (RHC), allowing for accurate hemodynamic measurements. They reported a PH prevalence of 27%, which is slightly lower than the 30% observed in our study.

Both studies highlighted a progressive increase in PH severity with increasing OSA severity. Bady et al. attributed this trend primarily to the hypoxic burden during apneic events, which was found to significantly influence pulmonary pressures. Our

findings align with this observation but are further supported by statistical modeling, which demonstrated that PH severity significantly improved the predictive accuracy for categorizing OSA severity. This reinforces the association between hypoxia-induced vascular changes and PH development in OSA patients, offering a more robust analytical perspective.

Srivastava et al.⁹⁹ evaluated 100 patients for PH using 2D echocardiography in a prospective observational study. They included both OSA and overlap syndrome patients and used standard echocardiographic criteria to define PH. Their focus was to examine the prevalence of PH across different respiratory conditions and its correlation with disease severity.

Their results showed an overall PH prevalence of 24%, with a significantly higher rate (36.7%) among those with overlap syndrome. In patients with isolated OSA, PH was observed in 5%. Compared to our study 30% prevalence among OSA-only patients, their lower rate could be due to differences in inclusion thresholds or diagnostic timing. Nonetheless, both studies highlight the utility of echocardiography and reinforce the clinical relevance of assessing PH risk. Our logistic regression analysis further confirmed that PH severity is not only prevalent but also a strong statistical predictor of advancing OSA severity.

Sajkov et al.¹⁰⁰ investigated 27 patients with moderate OSA (RDI > 10) using Doppler echocardiography. The primary objective was to explore the hemodynamic effects of OSA and to assess whether CPAP therapy could reverse PH. Their study included follow-up measurements after treatment to understand the reversibility of observed changes.

They found that 41% of patients had mild PH and that pulmonary artery pressures improved with CPAP therapy. While our study did not assess treatment

effects, the high prevalence found by Sajkov is in line with our findings and suggests that PH in OSA is often present but potentially reversible. Our results further contribute by statistically quantifying the association between PH severity and OSA classification, emphasizing the predictive value of PH in determining the extent of sleep-disordered breathing.

Maloney et al.¹⁰¹ studied 318 pediatric patients with severe OSA (OAHl ≥ 10), using echocardiography to detect PH. The aim was to assess the prevalence and correlates of PH in children undergoing evaluation for OSA, with a specific focus on comorbidities such as Down syndrome and hypoventilation.

The PH prevalence in their cohort was 8.2%, considerably lower than the 30% observed in our adult cohort. They found no significant association between PH and OSA severity in children. Instead, PH was more common among those with Down syndrome and sleep-related hypoventilation, underscoring important age-related differences in PH pathogenesis. In contrast, our study, which included three patients under 18 years of age, demonstrated a different pattern. One pediatric patient, diagnosed with Pickwickian syndrome, had severe PH and severe OSA, while the other two had normal PH. Through a multinomial logistic regression model, our findings highlighted that PH severity has a statistically significant impact on OSA classification, emphasizing a stronger direct link in adults.

Elfimova et al.¹⁰² conducted an observational study on 145 adults referred for sleep diagnostics, using echocardiography to estimate systolic pulmonary artery pressure. They aimed to identify the prevalence of PH and its association with OSA severity, oxygen desaturation, and obesity.

They found that 14.5% of participants had PH (systolic PAP > 40 mmHg), and those with PH exhibited higher AHI, ODI, and BMI. Compared to our study's 30%

prevalence, their lower percentage may reflect different population characteristics or definitions of PH. Still, the observed associations in both studies support the concept that OSA severity and obesity are important risk factors for developing PH. Moreover, our statistical findings support PH as a strong predictive factor for OSA severity, adding a novel analytical dimension to the clinical observation.

Discussion of Various risk factors associated with pulmonary hypertension in sleep apnea syndrome:

OBESITY

The present study demonstrates a significant correlation between the severity of obstructive sleep apnea (OSA) and the prevalence of pulmonary hypertension (PH) across various BMI categories, with progressively increasing PH severity observed in individuals with higher BMI and more severe OSA. This finding aligns with existing literature that underscores the role of nocturnal hypoxemia, intermittent hypoxia, and altered pulmonary vascular resistance as key mechanisms contributing to PH development in OSA patients.

In normal BMI individuals, a statistically significant relationship ($p = 0.001$) was observed between OSA severity and PH prevalence, consistent with findings from Alchanatis et al.¹¹⁸, who reported a similar association in non-obese OSA patients due to intermittent hypoxemia and reduced pulmonary compliance. In overweight individuals, the prevalence of PH remained statistically significant ($p = 0.000$), with PH cases predominantly observed in those with severe OSA. This trend mirrors the findings of Sajkov et al.¹¹⁹, who highlighted that OSA-induced hypoxemia, even in overweight individuals, promotes pulmonary vasoconstriction and endothelial dysfunction, thereby elevating PH risk.

In individuals classified as Obese Class I, the prevalence of mild to severe PH increased with worsening OSA, with 38.5% of severe OSA cases showing PH ($p = 0.028$). This observation is supported by Baguet et al.¹⁰⁷, who demonstrated that obesity exacerbates PH by promoting left ventricular diastolic dysfunction, impaired pulmonary compliance, and increased airway resistance. For Obese Class II and III categories, the association between severe OSA and PH became even more pronounced, with statistically significant p-values of 0.007 and 0.000, respectively. Notably, the higher prevalence of moderate and severe PH in these groups aligns with studies by Minai et al.⁹⁴, who reported that obesity-related hypoventilation and hypercapnia contribute to pulmonary vascular remodeling, further aggravating PH in severe OSA patients.

These findings emphasize the multifactorial etiology of PH in OSA, where obesity, nocturnal hypoxemia, intermittent airway obstruction, and cardiovascular dysfunction converge to heighten pulmonary arterial pressure. The statistically significant associations across BMI categories reinforce the importance of timely OSA diagnosis and intervention, particularly in individuals with obesity, to mitigate the risk of PH progression. Early continuous positive airway pressure (CPAP) therapy, weight management, and cardiovascular risk reduction strategies may play a critical role in improving pulmonary hemodynamics and preventing adverse cardiovascular outcomes in this high-risk population.

COPD

The prevalence of pulmonary hypertension (PH) among individuals with chronic obstructive pulmonary disease (COPD) and obstructive sleep apnea (OSA) varies across studies, with our findings suggesting no statistically significant

association ($p = 0.771$) between OSA severity and PH prevalence in COPD patients. In our study, severe OSA was most prevalent (66.7%) among COPD patients, with most cases presenting mild (3 cases) or severe PH (1 case), but no moderate PH cases. In contrast, only one case each of mild and severe PH was found among those with mild and moderate OSA, respectively. These results can be compared with studies by Chaouat et al.¹⁰³ and Minai et al.⁹⁴, both of which explored the relationship between COPD, OSA, and PH.

Chaouat et al.¹⁰³ reported that PH in COPD patients with OSA is generally mild to moderate, with severe PH being rare, aligning with our study where moderate PH was absent among COPD-OSA patients. Their study, however, found a stronger association between severe OSA and PH prevalence, while our study did not establish statistical significance. The small sample size ($n=6$) in our study may have contributed to this discrepancy, limiting the ability to detect significant associations. Similarly, Minai et al.⁹⁴ observed that COPD patients with coexisting OSA had a higher PH prevalence compared to those without OSA, particularly in cases with higher AHI and nocturnal desaturation. While this supports the idea that OSA contributes to PH development in COPD patients, our study does not show a clear OSA severity-dependent trend in PH prevalence.

Srivastava et al.⁹⁹, who reported a much higher prevalence of PH (36.7%) among overlap syndrome patients compared to just 5% in isolated OSA cases, our results show partial alignment in terms of increased PH in severe OSA. However, Srivastava's study found a significant relationship between overlap syndrome and PH, suggesting a more consistent and measurable impact of comorbid COPD. In contrast, our findings did not reach statistical significance, highlighting the limitations posed

by a small COPD subgroup and the potential need for a larger sample to better evaluate the PH burden in overlap syndrome.

The differences in our findings could be attributed to sample size limitations, variability in COPD severity, and differences in diagnostic methods (echocardiography vs. right heart catheterization). Additionally, individual variability in pulmonary vascular response to hypoxia could explain why some severe OSA cases develop only mild PH, while others progress to severe PH. Overall, while prior studies suggest a link between OSA severity and PH risk in COPD, our study does not establish a statistically significant association, emphasizing the need for larger, more comprehensive studies to confirm this relationship.

HYPERTENSION

The relationship between obstructive sleep apnea (OSA) severity and pulmonary hypertension (PH) prevalence in hypertensive (HTN) individuals is well-established, and our study further supports this association with a statistically significant p-value of 0.000. Our data indicate that as OSA severity increases, the prevalence and severity of PH also rise, with severe OSA cases exhibiting the highest burden of mild, moderate, and severe PH. These findings align with previous studies, including those by Pedrosa et al.¹⁰⁴ and Kohyama et al.¹⁰⁵, which explored the relationship between OSA, hypertension, and PH.

Pedrosa et al.¹⁰⁴ found that hypertensive individuals with moderate-to-severe OSA had significantly higher rates of PH compared to those with mild or no OSA. Their study also reported that the presence of PH was associated with increased nocturnal hypoxemia and elevated apnea-hypopnea index (AHI), similar to our findings where severe OSA individuals had the highest PH prevalence and severity.

This supports the notion that worsening OSA exacerbates pulmonary vascular dysfunction, especially in hypertensive individuals, leading to higher PH prevalence and severity in severe OSA cases. Additionally, the presence of mild PH in lower OSA severity groups, as seen in our data, suggests that even mild-to-moderate OSA contributes to early pulmonary vascular changes.

Similarly, Kohyama et al.¹⁰⁵ observed that hypertension and severe OSA synergistically increased the risk of developing PH, particularly in individuals with prolonged nocturnal oxygen desaturation and systemic inflammation. Their study found a higher prevalence of moderate and severe PH in severe OSA patients, comparable to our results, where five cases of moderate PH and two cases of severe PH were identified in the severe OSA group. The significant association observed in our study suggests that hypertensive individuals with severe OSA are at a much higher risk for PH, reinforcing the role of OSA-induced hypoxia and vascular remodeling in PH pathogenesis.

While our study and these previous findings strongly indicate a correlation between OSA severity and PH risk in hypertensive individuals, variations in sample size, diagnostic modalities (echocardiography vs. right heart catheterization), and population characteristics could contribute to minor differences in reported PH prevalence. Nevertheless, the overall trend across studies confirms that OSA severity is a key determinant of PH development in hypertensive individuals, emphasizing the need for early detection and management of OSA to mitigate pulmonary complications.

ISCHEMIC HEART DISEASE

The association between obstructive sleep apnea (OSA) severity and pulmonary hypertension (PH) in individuals with ischemic heart disease (IHD) is a crucial area of investigation, as both conditions contribute to significant cardiovascular morbidity. In our study, we observed that as OSA severity increased, the presence of PH also showed a rising trend, with a statistically significant p-value of 0.013. While most individuals (7 out of 9) had normal pulmonary pressure, one case of mild PH was reported in the severe OSA group, and one case of moderate PH was noted in the moderate OSA group. These findings suggest that OSA-related hypoxia and vascular changes may contribute to PH development in individuals with IHD, even though severe PH cases were absent in our cohort. This pattern can be compared with findings from Barlow et al.¹⁰⁶ and Baguet et al.¹⁰⁷, both of which explored OSA, IHD, and their impact on PH development.

Barlow et al.¹⁰⁶ reported that patients with IHD and moderate-to-severe OSA had a higher likelihood of developing PH, with worsening nocturnal hypoxia and increased pulmonary vascular resistance as contributing factors. Their findings align with our study, where moderate OSA cases exhibited moderate PH, and severe OSA cases showed the presence of mild PH. However, the absence of severe PH in our study might be attributed to the small sample size (n=9) and potential differences in baseline cardiac function. Additionally, Baguet et al.¹⁰⁷ demonstrated that PH prevalence is higher in hypertensive and ischemic heart disease patients with OSA compared to those without OSA, emphasizing the role of hypoxia-induced endothelial dysfunction and increased sympathetic activity in PH progression. Their study also identified a correlation between OSA severity and the degree of PH, which is consistent with our findings, where severe OSA had the highest PH prevalence, though mostly in the mild category.

The discrepancy in PH severity distribution across studies may be due to differences in sample size, diagnostic methods (echocardiography vs. right heart catheterization), and OSA management strategies. Furthermore, the absence of severe PH cases in our study may reflect early-stage pulmonary vascular involvement rather than advanced disease. Nonetheless, the significant association found in our study and corroborated by previous research underscores the need for early detection and intervention for OSA in IHD patients, as untreated OSA may accelerate pulmonary vascular remodeling and worsen cardiovascular outcomes.

HYPOTHYROIDISM

The relationship between obstructive sleep apnea (OSA) severity and pulmonary hypertension (PH) in individuals with hypothyroidism is complex, as both conditions can independently contribute to cardiovascular and pulmonary complications. In our study, we observed that while PH was present in individuals with moderate and severe OSA, the overall prevalence was low, and the association was not statistically significant ($p = 0.111$). Most individuals with mild and severe OSA had normal pulmonary pressure, with only a few cases of mild and moderate PH observed in the moderate and severe OSA groups, and no severe PH cases. These findings can be compared with those from Kansara et al.¹⁰⁸ and Zhang et al.¹⁰⁹, both of which explored the interaction between hypothyroidism, OSA, and PH.

Kansara et al.¹⁰⁸ reported that hypothyroidism is associated with an increased risk of PH, largely due to impaired pulmonary vasodilation, metabolic dysfunction, and endothelial abnormalities. Their study found that patients with both hypothyroidism and OSA had a higher likelihood of developing PH compared to those with OSA alone, which contrasts with our study where PH was not significantly associated with OSA severity in hypothyroid patients. This discrepancy may be due to

differences in thyroid disease severity, treatment status (levothyroxine therapy), and pulmonary vascular response to chronic hypoxia. Similarly, Zhang et al.¹⁰⁹ found that patients with untreated hypothyroidism had higher pulmonary artery pressures, and those with coexisting moderate-to-severe OSA had a significantly greater risk of developing PH. However, their study suggested that thyroid hormone replacement therapy mitigates PH risk, which might explain the low PH prevalence in our study if most participants were on thyroid medication.

The differences between our findings and previous studies may be due to small sample size (n=11), variations in thyroid disease management, and differences in OSA severity distribution. Additionally, since no severe PH cases were reported in our study, this may indicate that hypothyroidism alone is not a major driver of severe PH in OSA patients, but rather an exacerbating factor in combination with other cardiovascular risk factors. While prior research highlights a potential link between hypothyroidism, OSA, and PH, our findings suggest that OSA severity alone does not significantly impact PH prevalence in hypothyroid individuals, warranting further large-scale studies to clarify this relationship.

TYPE 2 DIABETES MELLITUS

The prevalence of pulmonary hypertension (PH) in individuals with type 2 diabetes mellitus (T2DM) and obstructive sleep apnea (OSA) suggests a significant association between OSA severity and the presence of PH, as indicated by the p-value of 0.005. In our study, PH was rare among individuals with mild and moderate OSA, with most participants having normal pulmonary pressure. However, as OSA severity increased, the prevalence of PH (mild, moderate, and severe) also rose, with severe OSA patients exhibiting the highest burden of PH (56.2%), compared to those with mild (16.7%) and moderate OSA (25%). These findings align with studies by

Tasbakan et al.¹¹⁰ and Kuniyoshi et al.¹¹¹, both of which demonstrated a strong link between OSA, T2DM, and PH, emphasizing the role of metabolic dysfunction and intermittent hypoxia in pulmonary vascular remodeling.

Tasbakan et al.¹¹⁰ found that T2DM patients with severe OSA had a significantly higher prevalence of PH than those with mild or moderate OSA, similar to our results. Their study highlighted that hyperglycemia and insulin resistance contribute to endothelial dysfunction, exacerbating hypoxia-induced pulmonary vasoconstriction, which may explain the progressive rise in PH with increasing OSA severity in our study. Furthermore, they reported that patients with both T2DM and OSA exhibited more pronounced nocturnal hypoxemia, a key driver of increased pulmonary artery pressure.

Similarly, Kuniyoshi et al.¹¹¹ investigated the relationship between T2DM, OSA, and cardiovascular complications, revealing that individuals with severe OSA had a significantly higher prevalence of PH compared to those with milder forms of sleep apnea. Their study suggested that chronic intermittent hypoxia, oxidative stress, and systemic inflammation—common in both T2DM and OSA—may lead to pulmonary vascular remodeling and increased pulmonary artery pressures. These mechanisms align with our findings, where severe OSA patients exhibited the highest rates of PH, including moderate and severe PH cases.

The consistent association between severe OSA and PH in individuals with T2DM across studies underscores the importance of early screening and intervention to prevent pulmonary vascular complications in this high-risk group. However, variations in study populations, diagnostic criteria for PH, and glycemic control levels may influence the degree of PH prevalence reported. Future research with larger sample sizes and longitudinal follow-up is needed to further explore the underlying

mechanisms and potential therapeutic strategies for managing PH in T2DM patients with OSA.

NOCTURNAL HYPOXEMIA

Our study identifies a significant inverse relationship between the severity of pulmonary hypertension (PH) and nocturnal hypoxemia in patients with obstructive sleep apnea (OSA). Specifically, as PH severity increases from normal to severe, mean nocturnal minimum SpO₂ levels decrease from 77% to 62%, with a strong negative correlation coefficient of -0.788 and a p-value of 0.000. This finding aligns with existing literature that underscores the impact of nocturnal hypoxemia on cardiovascular outcomes. A study done by Dommasch M et al.¹¹² demonstrated that nocturnal hypoxemia in OSA patients is a significant predictor of poor prognosis following myocardial infarction, suggesting that oxygen desaturation during sleep exacerbates cardiovascular risks.

Similarly, Inoue H et al.¹¹³ found that while sleep apnea itself was not directly associated with worse outcomes in patients with pulmonary arterial hypertension (PAH), nocturnal hypoxemia was linked to increased mortality. This emphasizes that continuous low oxygen levels during sleep may promote pulmonary vasoconstriction and remodeling, contributing to the progression of PH. This significant decline aligns with the findings of Kholdani et al.¹¹⁴, which indicated that severe nocturnal hypoxemia is a potent predictor of pulmonary vascular dysfunction. Similarly, our results align with Minic et al.¹²⁰, confirming that nocturnal hypoxemia plays a crucial role in PH development.

Nocturnal hypoxemia, assessed through minimum SpO₂ levels, exhibits a strong negative correlation with pulmonary hypertension severity. Patients with severe pulmonary hypertension show markedly lower nocturnal SpO₂ levels,

reinforcing the role of chronic intermittent hypoxia in pulmonary vascular remodeling and increased pulmonary pressures. This association underscores the necessity of targeted interventions such as continuous positive airway pressure (CPAP) therapy to alleviate hypoxemic stress and reduce pulmonary hypertension burden in OSA patients.

Collectively, these studies, along with our findings, highlight the critical role of nocturnal hypoxemia in the pathogenesis and progression of pulmonary hypertension among OSA patients. They suggest that monitoring and addressing nocturnal oxygen desaturation could be vital in mitigating cardiovascular risks and improving patient outcomes in this population

MODIFIED MALLAMPATI SCORE

Our study found a strong association between a high Modified Mallampati score (III-IV) and PH severity ($p = 0.000$). This is consistent with previous research by Koutsourelakis et al.¹¹⁵, which demonstrated that a high Mallampati score correlates with increased upper airway resistance, worsening OSA severity and consequently increasing the likelihood of PH.

The Modified Mallampati airway score, an indicator of upper airway obstruction, is found to be significantly associated with pulmonary hypertension. Higher Mallampati scores correspond with greater pulmonary hypertension prevalence, suggesting that anatomical airway narrowing may contribute to the development of elevated pulmonary pressures in OSA patients. This finding emphasizes the importance of airway assessment in OSA management and its implications for cardiovascular health.

REGRESSION ANALYSIS

In this study to identify the various others factors associated with increase PH, regression analysis has been done to reveal the other significant risk factors. The regression analysis revealed that hypertension ($R = 0.301$, $p = 0.023$), type 2 diabetes mellitus ($R = 0.215$, $p = 0.015$), and chronic obstructive pulmonary disease ($R = 0.271$, $p = 0.021$) were significantly associated with PH. These findings align with the work of Marin et al.¹¹⁶, who found that metabolic syndrome and respiratory diseases exacerbate pulmonary hypertension in OSA patients.

Several other factors were significantly associated with increased PH risk in OSA patients:

- Age > 50 years (OR: 2.10, $p = 0.035$)
- BMI ≥ 30 kg/m² (OR: 3.00, $p = 0.01$)
- Neck Circumference ≥ 40 cm (OR: 3.50, $p = 0.008$)
- Obesity Class II/III (OR: 4.10, $p = 0.015$)
- STOP-Bang Score ≥ 5 (OR: 4.00, $p = 0.003$)
- SpO₂ < 90% (OR: 5.00, $p = 0.001$)

These results corroborate studies by Chami et al.¹¹⁷ and Alchanatis et al.¹¹⁸, which emphasized the role of metabolic, cardiovascular, and anatomical factors in OSA-associated PH.

Compared to the findings by Sajkov & McEvoy¹¹⁹, our results reinforce the well-established link between OSA and PH but add greater specificity regarding risk factors and demographic influences. However, our findings differ slightly from Marin et al.¹¹⁶, who reported a weaker association between obesity and PH, possibly due to variations in sample characteristics and study methodologies.

This study underscores the strong association between OSA severity and pulmonary hypertension, with obesity, nocturnal hypoxemia, and hypertension emerging as key contributing factors. The statistically significant correlations between anthropometric parameters, comorbidities, and PH severity suggest that early intervention targeting weight reduction, cardiovascular health, and respiratory function could mitigate PH risk in OSA patients. Future longitudinal studies are needed to explore the mechanistic pathways linking OSA and PH, ultimately guiding more effective prevention and treatment strategies.

Likelihood ratio tests and regression analyses highlight the predictive value of pulmonary hypertension severity on patient outcomes. The model-fitting criteria demonstrate a significant relationship, with increasing severity of pulmonary hypertension associated with progressively lower outcome measures. Regression analysis of comorbidities identifies hypertension (HTN), type 2 diabetes mellitus (T2DM), chronic obstructive pulmonary disease (COPD), ischemic heart disease (IHD), and hypothyroidism as significant predictors of pulmonary hypertension. Among these, hypertension exhibits the strongest correlation, further emphasizing the interconnection between systemic and pulmonary vascular dysfunction in OSA patients. While each comorbidity contributes modestly to pulmonary hypertension variance, their collective impact underscores the need for a multidisciplinary approach in managing OSA-associated cardiovascular risks. Though our study population had other comorbidities such as CKD, OCD and Bronchial asthma there is no statistical significance because of less sample size.

Logistic regression analysis of risk factors reveals several significant predictors of pulmonary hypertension severity. Older age, BMI ≥ 30 kg/m², hypertension, increased neck circumference, higher obesity classes, elevated systolic

blood pressure, and low SpO₂ are all strongly associated with increased pulmonary hypertension severity. Among these, SpO₂ <90% emerges as the most critical predictor, with the highest odds ratio, indicating that nocturnal hypoxemia is a primary driver of pulmonary vascular changes in OSA patients. These findings reinforce the importance of timely intervention to optimize oxygenation and mitigate cardiovascular consequences.

Strength of the study

The study on the prevalence and correlates of pulmonary hypertension (PH) in patients with sleep apnea syndrome has several key strengths.

- Firstly, it utilizes an observational study design, enabling a real-world assessment of the association between sleep apnea severity and PH. The inclusion of comprehensive demographic, clinical, and comorbidity data provides a holistic view of risk factors, enhancing the robustness of findings.
- Secondly, the study employs statistical significance testing across multiple variables, ensuring the reliability of results. The stratification of patients based on BMI categories (normal, overweight, and different obesity classes) allows for nuanced insights into the impact of body weight on PH prevalence.
- Moreover, the identification of key predictors of PH in sleep apnea patients paves the way for early diagnosis and targeted interventions. The findings contribute valuable clinical knowledge that may guide improved management strategies for individuals at risk of cardiovascular complications associated with sleep apnea. Lastly, the study sets a strong foundation for future research on mechanistic links between sleep apnea and pulmonary hypertension, offering scope for interventional studies.

LIMITATIONS OF THE STUDY

- **Measurement Limitations** – The diagnosis of pulmonary hypertension often requires right heart catheterization, which is the gold standard. If the study relies on echocardiographic estimates alone, there may be a risk of overestimation or underestimation of PH prevalence.
- **Observational Nature** – Since this is an observational study, causality between sleep apnea and pulmonary hypertension cannot be established. The study can only identify associations, not direct cause-and-effect relationships.
- **Lack of Longitudinal Follow-Up** – The study design does not account for the progression of pulmonary hypertension in sleep apnea patients over time. A longitudinal study could provide more insights into the long-term impact of sleep apnea on pulmonary circulation.
- **Confounding Variables** – The study may not control for critical confounders such as obesity, smoking, alcohol consumption, medication use, and other metabolic conditions, which could affect the relationship between sleep apnea and pulmonary hypertension.
- **Limited Representation of Pediatric or Elderly Populations** – Although the inclusion criteria state "all age groups," there may be a lower representation of pediatric or elderly patients, which could impact the applicability of the findings to these populations.
- **Cross-Sectional Design** – If the study follows a cross-sectional design, it provides a snapshot of the relationship between sleep apnea and pulmonary hypertension without considering temporal changes or disease progression.

CONCLUSION

In conclusion, this study provides substantial evidence supporting the association between obstructive sleep apnea and pulmonary hypertension, highlighting the multifaceted interactions between demographic, anthropometric, physiological, and comorbid factors. The progressive increase in pulmonary hypertension prevalence and severity with worsening OSA underscores the critical need for early diagnosis and intervention. Weight management, cardiovascular risk assessment, and optimization of oxygenation through CPAP therapy or supplemental oxygen are essential strategies in mitigating the long-term cardiovascular burden in OSA patients. Additionally, the significant associations observed with comorbidities suggest that a holistic, multidisciplinary approach is required to address the broader implications of OSA on overall health. Future research should focus on long-term outcomes of pulmonary hypertension treatment in OSA patients, the efficacy of therapeutic interventions, and the exploration of novel biomarkers to enhance early detection and risk stratification. Through improved understanding and management, the clinical burden of pulmonary hypertension in sleep apnea syndrome can be significantly reduced, ultimately improving patient prognosis and quality of life.

SUMMARY

- The present study is an institution based prospective study conducted in a tertiary care hospital among OSA patients during the period of April 2023 -March 2024.
- The diagnosis of OSA was done based on Level II polysomnography according to AASM guidelines. The patients were subjected to transthoracic two dimensional echocardiography to diagnose pulmonary hypertension and assess its severity.
- A total of 70 patients diagnosed with obstructive sleep apnea (OSA) were included in the study. These were stratified into three groups based on OSA severity: Mild OSA (n=12), Moderate OSA (n=18), and Severe OSA (n=40). The mean age of the study population was comparable across all severity groups, with values being 53.92 ± 21.2 years in mild, 53.0 ± 12.57 years in moderate, and 52.82 ± 15.21 years in severe OSA.
- The overall prevalence of pulmonary hypertension (PH) in individuals with obstructive sleep apnea (OSA) is approximately 30%.
- As the severity of obstructive sleep apnea increased, the severity of pulmonary hypertension also increased, showing a statistically significant correlation.
- Weight, and BMI progressively increase with OSA severity, with the highest BMI observed in the severe OSA group (35.14 ± 6.09).
- A definitive conclusion regarding association of OSA, Pulmonary hypertension and lifestyle habits, such as alcohol consumption and smoking, could not be drawn ,as the sample size are minimal across all groups.
- Our study found a strong association between STOP-BANG questionnaire and high Modified Mallampati score (screening tools in OSA) in PH severity among OSA patients. However another salient screening tool that is neck circumference did not

show significance in OSA severity but showed a strong association with prevalence of Pulmonary hypertension and severity of pulmonary hypertension.

- Nocturnal hypoxemia measured by pulse oximeter had a significant correlation with severity of OSA and severity of pulmonary hypertension. . Also similar results were appreciated with daytime SpO₂.
- A strong association is observed between worsening OSA severity and increased PH prevalence, with statistically significant p-values across all BMI groups. This correlation underscores the importance of early intervention in managing OSA to reduce the risk of PH. The study establishes a crucial link between sleep apnea and pulmonary hypertension in those with higher BMI, paving the way for improved clinical management and future research on targeted interventions for high-risk patients.
- The prevalence of comorbidities such as hypertension (HTN), ischemic heart disease (IHD), chronic obstructive pulmonary disease (COPD), hypothyroidism, and type 2 diabetes mellitus (T2DM) is significantly higher in severe OSA cases and also has positive correlation with severity of PH.

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ANNEXURE I: - KAHERs JNMC

BELAGAVI

INFORMED CONSENT FORM

PREVALENCE AND CORRELATES OF PULMONARY HYPERTENSION IN PATIENTS WITH SLEEP APNEA SYNDROME- A OBSERVATIONAL STUDY

Name of Student/Principal Investigator: _____

Name of Guide/Co Investigators: _____

- Objective:**
1. Prevalence of pulmonary hypertension in sleep apnea syndrome
 2. Assess the severity of pulmonary hypertension with severity of sleep disorders.
 3. Various other risk factors associated with severity of pulmonary hypertension and sleep apnea syndrome

Introduction:

Sleep-disordered breathing (SDB) is characterized by discrete episodes of absent (apnea) or reduced (hypopnea) breathing, and/or by sustained reductions in breathing during sleep (hypoventilation) compared with wakefulness. The most common form of SDB results from closure of the upper airway during sleep and is called obstructive sleep apnea (OSA). The prevalence of OSA syndrome (AHI ≥ 5 with daytime sleepiness) is 4% in men and 2% in women¹, and the prevalence of AHI ≥ 15 or greater regardless of symptoms is 9% in men and 4% in women¹. The prevalence of OHS is estimated to be 10 to 20% in obese patients with obstructive sleep apnea and 0.15 % to 0.3 % in general population. SDB is diagnosed by polysomnography (PSG), which is a comprehensive multichannel sleep study, or by limited-channel home sleep apnea testing devices.

There are three different levels of sleep studies. Level 3 sleep study often referred to as a home sleep apnea test which records the breathing activity, oxygen levels and heart rate through out the course of the night. Level 2 sleep study also called polysomnography which is currently in our hospital, in addition to level 3 it monitors brain and muscle activities. Level 1 sleep study is same as the level 2 but it takes place in a sleep lab and always observed in real time by a registered polysomnographic technologist.

An apnea is defined as a cessation of breathing longer than 10 seconds. Hypopneas are associated with a reduction in air flow rather than complete cessation of airflow. These events are associated with a fall in oxygen saturation or a brief arousal from sleep (microarousal). These are episodes of mild upper airway narrowing during sleep, typically identified as flattening of the airflow signal from the nasal pressure cannula, with a reduction in flow amplitude not large enough to be scored as hypopnea, terminating with a microarousal. The standard metric for OSA severity is the apnea-hypopnea index (AHI), which is calculated as the number of apneas and hypopneas during sleep divided by total sleep time, represented in events per hour. OSA severity is graded as follows:

normal (no OSA): AHI less than 5; mild sleep apnea: AHI 5 or greater but less than 15; moderate sleep apnea: AHI 15 or greater but less than 30; and severe sleep apnea: AHI of 30 or greater.

The reported prevalence of pulmonary hypertension in OSA varies considerably between studies, ranging from 15–75%¹, although pooled data from several studies yielded a 10% prevalence (mean pulmonary artery pressure > 25 mm Hg at cardiac catheterization). Most OSA patients without major comorbidities have normal pulmonary artery pressures; pulmonary hypertension, when present, is mild. More severe pulmonary hypertension, in some instances leading to right ventricular dysfunction and right heart failure, may develop in patients with underlying lung function abnormalities (COPD, obesity restriction, neuromuscular disease), many of whom will present with daytime hypoxemia and hypercapnia.

The purpose of the study is to discuss the current knowledge around the consequences of sleep breathing disorders on pulmonary hemodynamics as well as the prevalence, severity and risk factors associated with pulmonary hypertension and sleep apnea syndrome.

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Explanation of procedure: 2D echocardiography

Withdrawal from participation in the study: Participation in this study is voluntary. You will be free to decide whether to participate in this study or continue participation once enrolled. In case you decide to withdraw your participation, you are free to do so. However, please convey the decision to the principal investigator.

Possible benefits from participating in the study: You will/will not have nor get any benefits by participating in this study. The data gathered will help the population at large.

Possible risks from participating in the study: There are no risks involved in participating in this study.

Privacy and confidentiality: The information collected from you will be coded, to prevent any person from identifying you. Your identity will never be revealed. The data collected from you will be kept confidential and only processed or aggregated data will be used for publication.

Financial incentives: You will not receive any payment for participating in this study.

Authorization for publication of aggregated data: Results obtained after processing of the aggregated data will be published for scientific purposes and or presented to scientific groups. However, your identity will never be revealed.

Questions: In case of any questions with regard to this study, you are free to contact: “Dr.

_____’ If you have any question or complaints with regard to your right as study participant you may contact Dr Harsha Hegde, Chairperson, Ethical committee of JNMC, 0831-2473777 Extension 4052.

Legal rights: By signing this consent form, we are not waiving any of your legal rights.

CONSENT STATEMENT

I am making a voluntary decision to participate in the study “PREVALENCE AND CORRELATES OF PULMONARY HYPERTENSION IN PATIENTS WITH SLEEP APNEA SYNDROME- A OBSERVATIONAL STUDY”. My signature below indicates that I have decided to participate and I have read the information provided above or the information provided above has been read to me in the language that I understand best. I was given the opportunity to ask questions and that they have been answered to my satisfaction.

Name of the participant:

Signature or left thumb impression of the participant:

Name of the witness:

Signature or left thumb impression of the witness:

Name of the investigator:

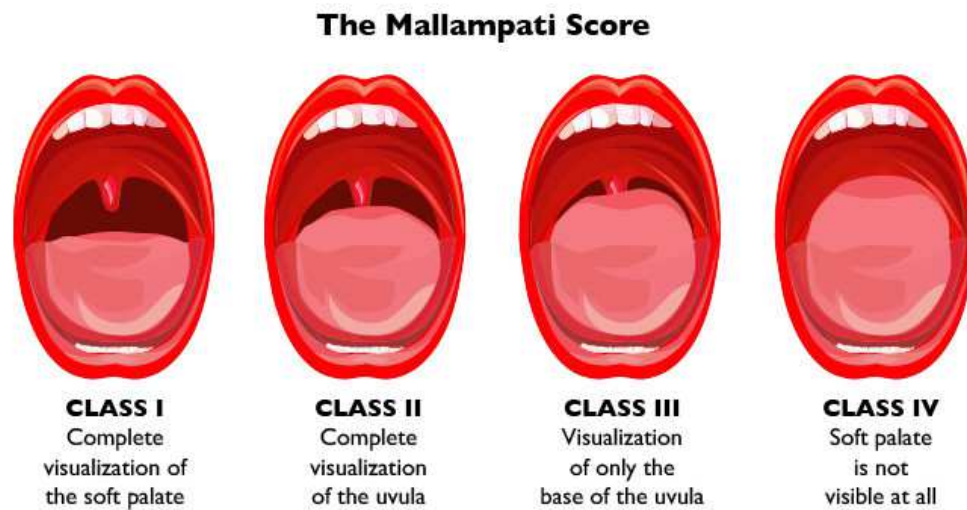
Signature of the investigator:

ANNEXURE II :- PROFORMA

DATE	
NAME	
AGE	
SEX	
IP NO	
HEIGHT	
WEIGHT	
BMI	
NECK CIRCUMFERENCE	
ADDRESS WITH PHONE NUMBER	
MARITAL STATUS	
OCCUPATION	

CHIEF COMPLAINTS	
CO MORBIDITIES	
FAMILY HISTORY	
ADDICTIVE HABITS	
VITALS	BP -
	PR -
	SPO2 -
MODIFIED MALLAMPATI AIRWAY SCORING	
EPWORTH SLEEPINESS SCALE	
APNEA HYPOPNEA INDEX	
SEVERITY OF SLEEP APNEA	
PULMONARY ARTERY PRESSURE AND SEVERITY	
STOP BANG SCORE	
NOCTURNAL HYPOXEMIA SpO ₂	

Modified Mallampati score



STOP-BANG questionnaire:

The mnemonic STOP- BANG includes the following:

- S: “Do you snore loudly, loud enough to be heard through a closed door?”
- T: “Do you feel tired or fatigued during the daytime almost every day?”
- O: “Has anyone observed that you stop breathing during sleep?”
- P: “Do you have a history of high blood pressure with or without treatment?”
- B: BMI > 35 kg/m²
- A: Age > 50 years
- N: Neck circumference > 43 cm (17 in)
- G: Gender, male

When more than three items are positive

Epworth sleepiness scale:

In contrast to just feeling tired, how likely are you to doze off or fall asleep in the following situations? (This refers to your usual life in recent times. Even if you have not done some of these things recently, try to work out how they would have affected you.) Use the following scale to choose the most appropriate number for each situation:

- 0 = Would never doze
- 1 = Slight chance of dozing
- 2 = Moderate chance of dozing
- 3 = High chance of dozing

Situation	Chance of Dozing
Sitting and reading	_____
Watching TV	_____
Sitting inactive in a public place (i.e., a theater or a meeting)	_____
As a passenger in a car for an hour without break	_____
Lying down to rest in the afternoon when circumstances permit	_____
Sitting and talking to someone	_____
Sitting quietly after lunch without alcohol	_____
In a car, while stopping for a few minutes in traffic	_____

scored 0–24, with >10 considered abnormal.

no	Age	Sex	Height (cm)	Weight (Kg)	BMI	Obese Class	Neck circumference	Habits	comorbidities	stop Bang score	BP	PR	Daytime Spo2	Modified mallampati airway scoring	Epworth sleepiness scale	AHI	severity of OSA	PA pressure	Degree of pulmonary hypertension	nocturnal hypoxemia min SpO2
1	16	M	155	44	18.3	Underweight	26	nil	nil	3	110/70	90	94	I	20	94.8	severe	23	Normal	71
2	9	M	124	60.5	39.3	II	28	nil	nil	4	100/60	96	85	III	20	50	severe	70	severe	65
3	7	F	122	39.5	26.5	Overweight	38	nil	nil	2	120/70	96	98	III	18	8.6	Mild	25	normal	88
4	55	M	155	105	43.7	III	41	nil	T2DM,IHD,hypothyroidism	6	130/90	100	96	III	18	43.9	severe	24	Normal	70
5	63	F	161	107	41.3	III	40	nil	T2DM,IHD,HTN,Hypothyroidism	6	120/90	88	92	III	18	68.8	severe	22	normal	72
6	69	F	158	98	39.3	II	39	nil	T2DM,HTN,Hypothyroidism	6	120/80	90	90	III	19	16.4	moderate	35	mild	94
7	54	F	152	103	44	III	38	nil	T2DM,HTN,Hypothyroidism	6	140/80	90	97	IV	14	11	Mild	22	Normal	51
8	73	M	166	100	36.3	II	41	smoker	T2DM,HTN,COPD,CKD	7	140/90	86	82	III	17	6.6	Mild	40	mild	82
9	60	M	162	68	25.9	Overweight	38	nil	T2DM,HTN	5	120/80	90	95	III	16	9.2	Mild	24	Normal	95
10	66	M	158	54	21.6	Normal	38	nil	T2DM,HTN	5	120/80	90	96	II	15	12	mild	22	normal	96
11	56	F	156	97	39.9	II	44	nil	T2DM,HTN, Bronchial Asthma	8	130/80	90	90	IV	20	55	severe	70	severe	68
12	48	F	158	98	39.3	II	44	nil	T2DM,HTN	8	100/60	90	80	IV	18	50	severe	50	moderate	70
13	35	F	162	126	48	III	45	nil	T2DM,HTN	6	130/90	60	89	IV	10	49	severe	55	moderate	78
14	53	M	170	114	39.4	II	43	nil	T2DM,HTN	8	130/80	94	94	III	18	41.6	severe	23	Normal	63
15	48	M	165	95	34.9	I	42	nil	T2DM, HTN, OCD	5	130/80	88	97	III	14	81	severe	24	Normal	75
16	55	F	161	85	32.8	I	39	nil	T2DM,HTN	6	120/80	90	96	IV	19	82.1	severe	23	Normal	80
17	52	M	158	111	44	III	42	nil	T2DM,HTN	7	120/70	110	79	IV	17	43.7	Severe	24	Normal	65
18	76	M	158	84	33.6	I	41	Nil	T2DM,HTN	7	110/70	102	94	III	18	30.4	severe	38	mild	75
19	56	F	167	82	29.4	Overweight	38	Nil	T2DM,HTN,COPD	4	130/80	87	97	III	20	47.1	severe	40	Mild	72
20	91	M	166	110	39.9	II	44	Nil	T2DM,HTN,COPD	8	130/80	90	85	IV	19	60.4	severe	42	mild	68
21	59	M	179	84	26.2	Overweight	41	nil	T2DM	5	120/80	90	96	III	16	33.7	Moderate	22	Normal	81
22	35	M	158	83	33	I	47	Nil	T2DM	4	130/80	90	86	III	13	15	moderate	25	Normal	61
23	52	F	158	98	39.3	II	44	Nil	T2DM	5	130/80	90	92	IV	20	70	severe	23	Normal	70
24	69	M	167	97	34.8	I	42	smoker	T2DM,COPD	5	130/80	88	86	III	18	25	Moderate	70	Severe	46
25	63	M	173	83	27.7	Overweight	38	smoker	T2DM,HTN,IHD	5	130/80	84	97	III	18	15.5	Moderate	24	Normal	85
26	61	M	160	102	39.8	II	43	Nil	T2DM,HTN,IHD	6	130/80	90	90	III	16	20	Moderate	24	Normal	80
27	57	M	167	79	28.3	Overweight	38	nil	T2DM,IHD	4	100/60	80	97	III	16	9.6	Mild	26	Normal	97
28	50	M	158	78	31.2	I	40	Nil	hypothyroidism	6	120/80	90	98	III	17	61	Severe	23	Normal	75
29	69	F	155	100.5	41.6	III	42	nil	HTN,Hypothyroidism	7	140/80	84	63	IV	21	73.8	Severe	60	Moderate	61
30	64	M	158	90	36.1	II	43	nil	HTN,Hypothyroidism	7	120/80	86	98	IV	18	22	Moderate	55	Moderate	82
31	40	F	164	84	31.2	I	41	nil	Hypothyroidism	3	130/80	108	91	III	20	10.2	mild	22	Normal	77
32	49	F	161	79.8	30.8	I	39	nil	HTN,Hypothyroidism,IHD,RA,Moderate MR	4	130/80	90	90	II	18	29	Moderate	55	moderate	85
33	65	M	170	92	31.8	I	40	Nil	HTN	6	110/70	90	96	III	14	22	Moderate	24	Normal	83
34	58	M	179	119	37.1	II	43	Alcoholic	HTN	8	140/80	80	80	IV	18	33.8	severe	25	Normal	74
35	60	M	160	92	35.9	II	43	Nil	HTN	5	130/80	70	92	IV	14	72.7	Severe	23	Normal	47
36	46	M	167	108	38.7	II	42	nil	nil	5	130/80	100	97	III	17	37	severe	24	Normal	87
37	46	M	172	104	35.2	II	44	nil	HTN	8	130/90	70	97	III	17	39	severe	24	Normal	75
38	55	M	158	106	42.5	III	42	nil	HTN	8	130/80	76	98	III	17	49.2	Severe	23	Normal	65
39	48	F	152	98	42.4	III	42	nil	HTN	6	130/80	100	85	IV	15	53.3	severe	40	mild	73
40	77	F	173	107	35.8	II	41	nil	Nil	6	130/80	62	95	III	18	5.2	Mild	35	Mild	88
41	39	M	176	90	29.1	Overweight	39	nil	nil	5	120/80	86	95	III	16	25	Moderate	23	Normal	85
42	45	F	152	98	42.4	III	40	nil	nil	5	110/70	80	94	III	16	20	Moderate	25	Normal	80
43	51	M	170	92	31.8	I	42	nil	nil	5	120/80	90	98	III	14	46.2	severe	24	Normal	84
44	47	M	166	93	33.7	I	42	nil	nil	5	130/80	90	96	III	17	60	Severe	23	Normal	70
45	62	M	170	106	36.7	II	42	nil	nil	6	130/80	80	96	IV	14	71.8	Severe	42	Mild	68
46	54	M	170	73	25.3	Overweight	43	nil	HTN,IHD	6	130/80	80	96	III	16	43	Severe	24	Normal	81
47	80	M	176	95	30.7	I	44	nil	HTN, IHD	6	120/80	90	96	III	14	66	Severe	38	Mild	84
48	62	F	158	92	36.9	II	44	nil	HTN,COPD	7	140/80	98	75	III	14	severe	40	mild	55	
49	85	M	185	87	25.4	Overweight	40	smoker	HTN,	7	130/70	86	80	III	16	6	mild	22	normal	54
50	65	F	164	88	32.7	I	42	nil	T2DM,HTN	6	140/80	90	80	IV	16	25	Moderate	25	normal	93
51	41	F	155	93	38.7	II	40	nil	nil	4	140/90	110	99	III	15	44.5	severe	24	normal	80
52	37	M	176	108	34.9	I	41	nil	nil	4	120/80	86	98	III	16	81.4	severe	25	normal	70
53	52	M	176	96	31	I	40	smoker	T2DM,HTN	6	130/90	90	94	III	18	29	Moderate	24	normal	66
54	29	M	164	65	24.2	Normal	40	nil	nil	4	120/80	90	98	III	17	69.5	severe	22	Normal	65
55	26	M	164	64	23.8	Normal	39	nil	nil	4	120/80	86	96	III	18	15.7	moderate	24	Normal	91
56	36	M	173	95	31.7	I	41	nil	nil	4	120/80	90	96	III	16	44.2	severe	25	normal	72
57	49	M	173	88	29.4	Overweight	42	nil	nil	4	120/80	86	99	III	18	69	severe	22	Normal	65
58	58	M	161	67	25.8	Overweight	39	Smoker	HTN	6	130/80	90	95	III	16	42.2	severe	23	normal	75
59	43	F	155	78	32.5	I	39	Nil	T2DM,HTN,CKD	5	130/80	98	96	III	14	14.3	Mild	22	Normal	85
60	45	M	170	85	29.4	Overweight	40	nil	HTN	5	130/80	88	96	III	16	18.5	moderate	24	Normal	85
61	50	F	160	70	27.3	Overweight	38	nil	Nil	4	120/70	90	98	II	14	12.3	mild	22	Normal	88
62	60	M	168	90	31.9	I	42	smoker	T2DM,HTN	7	140/90	92	94	IV	18	55.6	severe	50	moderate	70
63	35	F	155	60	25	Normal	37	nil	nil	3	110/70	84	97	II	15	8.9	Mild	24	Normal	90
64	55	M	172	95	32.1	I	43	nil	HTN,Hypothyroidism	6	130/80	90	95	III	17	35.4	severe	24	Normal	75
65	48	F	158	75	30	I	39	nil	HTN	5	120/80	88	96	III	16	22.7	Moderate	23	Normal	85
66	65	M	175	100	32.7	I	44	smoker	T2DM,HTN,COPD	8	140/80	86	92	IV	19	68.9	severe	70	Severe	68
67	42	F	162	68	25.9	Overweight	38	nil	Nil	4	120/70	90	98	II	14	22.7	Moderate	25	Normal	85

no	Age	Sex	Height (cm)	Weight (Kg)	BMI	Obese Class	Neck circumference	Habits	comorbidities	stop Bang score	BP	PR	Daytime Spo2	Modified mallampati airway scoring	Epworth sleepiness scale	AHI	severity of OSA	PA pressure	Degree of pulmonary hypertension	nocturnal hypoxemia min SpO2
68	70	M	170	85	29.4	Overweight	41	nil	HTN,IHD	6	130/80	90	94	III	17	68.9	severe	22	Normal	70
69	58	F	160	80	31.3	I	40	nil	HTN,Hypothyroidism	5	120/80	88	96	III	16	28.4	Moderate	23	Normal	85
70	60	M	168	90	31.9	I	42	smoker	T2DM,HTN	7	140/90	92	94	IV	18	55.6	severe	50	moderate	70