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Assessing the Impact of Asthma on Cardiopulmonary Metrics in Patients with Obstructive Sleep Apnea

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Abstract— **This study explores the relationship between obstructive sleep apnea (OSA) and asthma, focusing on the impact of asthma attacks on nocturnal cardiopulmonary metrics in individuals with moderate OSA. Polysomnography data from 38 subjects with and without asthma attacks were analyzed to extract pre- and post-sleep metrics related to heart rate, heart rate variability, oxygen saturation, and hypopnea events. A significant difference was found in the percentage of time spent in Stage 2 of non-rapid eye movement sleep between subjects with and without asthma. Additionally, significant differences were found in arterial oxygen saturation pre- and post-sleep in the non-asthma group. Future research should further explore temporal patterns and variations across sleep stages, apnea events, and hypopnea events to better understand the intricate relationship between asthma and OSA.**

Keywords— **Obstructive sleep apnea, Asthma, Polysomnography, Cardiopulmonary metrics**

I. Introduction

Obstructive sleep apnea (OSA) and asthma are common long-term respiratory disorders that often coexist and cause sleep disturbances. OSA is a sleep-related breathing disorder involving recurrent episodes of obstruction of the upper airway, resulting in hypoxia, loud snoring, and sleep fragmentation [1,2]. Asthma is a chronic inflammatory disease of the airways characterized by symptoms such as wheezing, shortness of breath, and coughing [1,3]. A bidirectional relationship has been demonstrated between these conditions, with each impacting the severity of the other [1-4]. Although OSA and asthma share a similar pathophysiology and their coexistence has been associated with impaired sleep architecture, the direct consequence of asthma on the expression of OSA symptoms remains poorly understood [3,5,6].

In contrast to the research demonstrating a higher prevalence of OSA in individuals with asthma, more work is needed to describe the development of asthma in OSA and the resulting effects on disease progression [7]. Asthma is independently associated with nocturnal symptoms related to bronchoconstriction, wheezing, and oxygen desaturation. This leads to ventilatory instability and upper-airway collapse during sleep, enhancing the severity of OSA through more frequent exacerbations [3,7-9]. The chronic systemic inflammation that exists in asthma also further aggravates the inflammation in OSA, triggering bronchial hyperresponsiveness [10]. To further clarify and quantify this relationship, it is necessary to explore how the presence of asthma modulates the expression of OSA through the investigation of objective sleep variables [3,10].

Polysomnography (PSG) is the gold standard for diagnosis of OSA. PSG is a multi-parametric test that monitors brain waves, muscle activity, eye movement, cardiac function, chest and abdomen movement, blood oxygen saturation, and breathing patterns [4]. This allows for the extraction of metrics such as the apnea-hypopnea index (AHI), which is widely used to diagnose and classify OSA. Apnea is defined as the absence of airflow for at least 10 seconds, while hypopnea is defined as a >50% decrease in airflow for at least 10 seconds or a moderate reduction in airflow (<50%) for at least 10 seconds with at least 4% oxygen desaturation. The AHI is calculated as the total number of apneas and hypopneas per hour of sleep [11]. Due to the significant overlap between the conditions, patients with OSA are inadequately screened and are underdiagnosed with underlying asthma, adversely affecting control of OSA and quality of life [1,3,10].

The objective of this study is to evaluate nocturnal cardiopulmonary metrics extracted from PSG tests from individuals with OSA to compare those with and without asthma attacks. Specifically, this work will consider the first and last 15 minutes of data for each metric, which will be referred to as pre- and post-sleep, respectively. The difference in time duration in each stage of sleep will also be investigated between groups. This will allow for the generation of meaningful statistics and identification of representative features, providing a better understanding of the physiological changes due to asthma in patients with OSA.

II. Methods

To achieve the objectives of this study, overnight PSG data comprising 38 subjects from the Sleep Heart Health Study (SHHS) was utilized [12]. This is an ongoing cohort study conducted across various centers. All patients were diagnosed with moderate OSA, based on an AHI score between

15 and 30. According to a clinical diagnosis of asthma based on the Global Initiate for Asthma guidelines, patients were divided into asthma (19 subjects) and non-asthma (19 subjects) groups. We selected participants for two groups in each group to match demographic characteristics and health conditions on a one-to-one basis [12].

Cardiopulmonary signals of interest from the PSG included heart rate (HR), arterial oxygen saturation (SaO_2), and electrocardiogram (ECG). Prior to feature extraction, preprocessing was performed on the raw data using Python. Delta and block filtering of the oxygen saturation data was implemented with appropriate thresholds to address missing values and artifacts. The delta filter discarded consecutive samples greater than 4% apart since these are considered non-physiological. Additionally, error values of less than 50% were removed along with 20 seconds of surrounding data. Similarly, discrete wavelet transform (DWT) and median filtering were applied to the ECG data to remove noise and baseline wandering. As done by Rashmi et al. [13], DWT was applied by decomposing the ECG signal into 7 levels using the Symlet wavelet with 8 vanishing moments (sym8). To perform denoising, the highest coefficients were set to zero while the remaining were subject to soft thresholding. The modified coefficients were then used for reconstruction. To remove baseline drift, two moving window median filters were applied with window sizes of 200 ms (remove QRS complex and P-wave) and 600 ms (remove T-wave). The filtered ECG signal was obtained by subtracting the outputs from the original signal [14].

Cardiopulmonary metrics of interest such as statistics from the HR, heart rate variability (HRV), arterial oxygen saturation, oxygen desaturation index (ODI), and hypopnea events were then extracted since these are suspected to contain differences within the context of asthma [15]. To determine the HRV for each subject, peak detection was performed on the ECG data using the Pan-Tompkins algorithm to extract the RR intervals. Common metrics including mean, standard deviation (SD), minimum, and maximum were then extracted for comparison [16]. ODI, commonly used to evaluate nocturnal hypoxemia severity, refers to the average number of desaturation episodes occurring per hour of sleep. A desaturation episode is a decrease in mean oxygen saturation by at least 3% for at least 10 seconds. These events were detected from the oxygen saturation data using the algorithm developed by Jung et al. [17].

Following the extraction of relevant features, the data were exported to JMP files to conduct a statistical analysis. Firstly, summary statistics were gathered for all pre-and post-sleep metrics between both groups. Boxplots were created for further visualization of the distributions. Hypothesis testing for normality and equal variance was then conducted for each combination of variables. Comparisons for pre- and post-sleep metrics across the two groups (asthma and non-asthma) were performed using a two-way ANOVA test. Finally, the differences in the percentage of total sleep duration in non-rapid eye movement (NREM) and rapid eye movement (REM) sleep stages were evaluated using t-tests. The NREM stage considers three phases. Stage 1 (N1) refers to light sleep, where breathing tends to occur at a regular rate, and lasts 1 to 5 minutes. Stage 2 (N2) is characterized by deeper sleep, leading to decreased heart rate, and typically lasts 25 minutes. The deepest non-REM sleep occurs in Stage 3 (N3). Approximately 90 minutes after falling asleep, the REM stage begins. This phase is associated with an erratic and irregular breathing rate, increased brain oxygen use, and increased and variable pulse. The presence of asthma or OSA is typically associated with reduced REM sleep due to nocturnal respiratory symptoms [18].

III. Results

The demographic variables for each group are summarized in Table 1 (mean ± SD).

Table 1 Participants Demographics

Characteristic	Asthma (n = 19)	Non-Asthma (n = 19)
Sex (male/female)	10/9	10/9
Age, years	61.7±8.0	61.5±7.5
Body Mass Index (BMI), kg/m^2	29.6±5.7	30.0±5.7
Neck Circumference, cm	38.6±4.5	40.0±4.6
Epworth Sleepiness Scale (ESS) Score	8.3±4.1	10.6±5.3
AHI, events/hour	32.4±8.6	38.0±18.9

Following preprocessing and the extraction of relevant features, a delta value between the means of the asthma and non-asthma groups and pre- to post-sleep were calculated, presented in Tables 2 and 3 respectively. A sample of the boxplots for the data is provided in Figure 1. The ANOVA and t-tests were then conducted with a significance level of 0.05. The resulting significant p-values are provided in Tables 2 and 3.

Table 2 Statistically Significant Features between Asthma and Non-Asthma Groups of Participants with OSA

Feature	Delta	p-value
Sleep Duration in N2, %	7.4±3.5	0.04

Table 3 Statistically Significant Features from Pre- to Post-Sleep in Non-Asthma group of Participants with OSA

Feature	Delta	p-value
Mean SaO_2, %	2.0±1.5	0.02
SD SaO_2, %	1.3±1.6	0.01
Minimum SaO_2, %	7.7±7.7	0.01

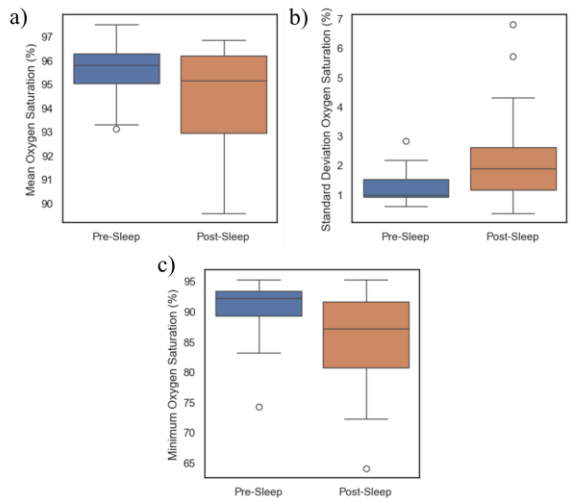

Fig. 1 a) Mean, b) Standard deviation (SD), and c) Minimum of Arterial Oxygen Saturation (SaO_2) from Pre to Post-Sleep in Participants with OSA and without Asthma

IV. Discussion

The objective of this study was to evaluate nocturnal cardiopulmonary metrics extracted from PSG tests in individuals with OSA and discern distinguishable patterns between those with and without asthma attacks. Since the demographics were matched between asthma and non-asthma patients, there were no significant differences in sex, age, BMI, neck circumference, ESS scores, or AHI. The results of the t-tests demonstrate a significant difference in the percentage of total sleep duration in N2. Additionally, significant differences were found in arterial oxygen saturation pre- and post-sleep in the non-asthma group.

In contrast to previous work demonstrating that the presence of asthma decreases mean nocturnal SaO_2 in those with OSA [19], no significant differences were observed between the asthma and non-asthma groups when considering the RR-interval, HR, and SaO_2 metrics. This result can likely be attributed to the smaller sample size of the data employed in this study, as further discussed in following sections.

The significant changes reported in pre- to post-sleep SaO_2 metrics in the non-asthma group align with previous research, which demonstrates differences in SaO_2 between the first and all other hours of sleep in subjects with OSA [20]. However, no significant results were found from pre- to post-sleep in subjects with both asthma and OSA. This can be attributed to the lack of asthma control in this study. As concluded by [19], mean SaO_2 levels in OSA patients vary between severe and moderate asthma, meaning asthma must be controlled to determine significant pre- and post-sleep differences.

The significant difference found in the duration of time spent in N2 between the asthma and non-asthma groups also supports previous findings [21,22]. Independently, asthma is characterized by airway inflammation and constriction, resulting in heightened respiratory effort and compromised airflow during sleep. In the presence of OSA, asthma worsens the susceptibility to nocturnal breathing disturbances, resulting in more frequent transitions from deeper sleep stages to N2 [3,8]. As a result, sleep architecture is further disrupted, leading to a higher proportion of time spent in N1 and N2 of NREM sleep for those with both conditions.

A limitation of this study was the inability to compare all features before and after the occurrence of apnea and hypopnea events due to lack of time syncing between metrics. This presented a barrier to conducting analysis of the temporal dynamics surrounding these events and how they may differ between the groups with and without asthma. Future investigation should therefore involve a more comprehensive feature-by-feature comparison to identify additional temporal patterns and variations.

Additionally, the relatively small size of the study population is an important consideration when interpreting the results. The limited sample size may have hindered the ability to fully capture the intricate relationship between OSA and asthma and produce generalizable results, especially with the lack of asthma control. The inherent variability of both conditions and their coexistence demands a larger cohort to extract robust conclusions, as shown in [19].

Future work should also investigate additional features along with more sophisticated analysis methods to identify subtle patterns [23]. It is possible that the cardiopulmonary signals used in this study may not capture the entirety of nocturnal interactions between OSA and asthma. Incorporating additional modalities such as electroencephalography, electromyography, electrooculography, spirometry, or sound analysis could offer a more comprehensive evaluation of nocturnal events [23]. These complementary features could reveal nuances in respiratory patterns, arousals, or other physiological parameters that are more relevant for distinguishing

OSA with and without asthma attacks. A multi-model approach may therefore enhance the sensitivity of results and provide a better understanding of the interactions between these conditions.

V. Conclusion

This study aimed to assess nocturnal cardiopulmonary metrics in individuals with OSA and discern patterns associated with asthma attacks. Overall, a significant difference was found in the percentage of time spent in N2 of NREM sleep between subjects with and without asthma. This is due to elevated susceptibility to nocturnal breathing disturbances, resulting in a further impaired sleep architecture. Additionally, significant differences were found in arterial oxygen saturation pre- and post-sleep in the non-asthma group, supporting previous findings.

This work reinforces the complex interaction between OSA and asthma and demonstrates the complicated nocturnal symptoms. Further investigation should consider a larger sample size and more detailed analysis of temporal patterns surrounding nocturnal events to better understand this intricate relationship.

Conflict of Interest

The authors declare that they have no conflict of interest.

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