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The impact of cigarette smoking on the quality of sleep in Polish men

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ABSTRACT: Quality of sleep directly impacts quality of life, whilst lifestyle significantly impacts night rest. Cigarette smoking is a serious threat to overall health, including sleep. Nicotine in cigarettes affects the nervous system, whilst the respiratory system is impacted by carcinogenic substances, such as dusts and tarred substances, inhaled with smoke. Cigarettes are assumed to be a risk factor in sleep disorders, including breathing sleep disorders.

This study's aim was to analyze the impact of cigarette smoking on adult men's polysomnographic parameters.

Polysomnographic records for 94 adult men were obtained from the polysomnography laboratory in Opolskie Province, Poland. Additionally co-morbidities, height, weight and frequency of smoking were also noted. Three groups of men were categorised according to the frequency with which they smoked: non-smokers, smoking less than a pack a day, smoking more than a pack a day.

Compared to non-smokers and mild smokers, men who were heavy smokers also exhibited the longest sleepless time (H=8.11; p=0.017), the maximum waking time following the onset of sleep (H=7.99; p=0.018), the lowest sleep efficiency across the three groups (H=7.96; p=0.019), the greatest number of apnea events per hour of sleep (H=6.23; p=0.045), the lowest Oxygen Level Nadir (H=11.44; p=0.003) and the highest rate of limb movements per hour of sleep (H=9.81; p=0.007).

The dose effect was identified, which correlated more cigarettes men smoked per day with lower sleep quality.

KEY WORDS: sleep apnea, polysomnography, snoring, nicotine

Introduction

Sleep is a physiological, reversible state of reduced consciousness, in which the somatic system activity is reduced whilst central nervous system activity is increased. There are four stages of sleep, three of which relate to non-rapid eye movement sleep (NREM) and one to rapid eye movement sleep (REM) (Krishnan and Collop 2006; Reite et al. 2009). During NREM phases, the brain gener-

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ates slow waves – hence the name slow-wave or deep sleep – contributing to the whole body's restoration, especially the nervous system. During the REM phase, brain wave activity and eye movement are elevated, along with hypotonicity and dream occurence. Consecutive sleep phases NREM 1, NREM 2, NREM 3 and REM represent the common sleep architecture of sleep cycles, with each phase recurring through the night and lasting about 90 minutes (Reite et al. 2009). Good quality sleep, particularly deep sleep, is vital for proper regeneration, and maintenance of cognitive functions and memory. The functionality of bodily systems, such as the endocrine and immune system, is dependent on proper night-time restoration (Carley and Farabi 2016). Both quality and quantity of sleep play a significant role in maintaining an organism's well-being. Lower sleep quality is known to alter normal stress response, resulting in either more exaggerated or blunted responses in relation to cortisol levels (Bassett et al. 2015). Poor sleep quality is also a risk factor for mental health problems, such as depression and anxiety (Slaven et al. 2011). A reduction in the quality and quantity of sleep can lead to a consequent reduction in immune system efficiency, increasing people's susceptibility to infections (Bryant et al. 2004). Specific forms of abnormal sleep patterns or, abnormal quality of sleep, are sleep disorders.

Sleep disorders comprise a vast group of disorders, according to the ICSD-3 (International Classification of Sleep Disorders-Third Edition), and include: insomnia, sleep-related breathing disorders, central disorders of hypersomnolence, circadian rhythm sleep-wake disorders, parasomnias, sleep-related movement disorders, as well as a range of other sleep disorders (Sateia 2014).

Risk factors that contribute to poor quality of sleep are numerous. Primarily they are lifestyle factors such as an inconsistent sleep schedule, psychological stress, inappropriate sleep hygiene or abuse of stimulants, such as caffeine, alcohol or cigarettes. (Ohayon et al. 2001; Riemann et al. 2001).

Apart from being a risk factor for numerous diseases including lung diseases, cardiovascular diseases or cancers, smoking cigarettes is also a risk factor for sleep disorders (West 2017). Cigarette smoking impacts the body through carcinogenic substances, such as dusts and tarred substances, inhaled with smoke, as well as through nicotine – a psychoactive chemical in tobacco – which results in dependency (West 2017). The occurrence of sleep disorders can be impacted by both cigarette smoking and cigarette cessation, resulting in: increased episodes of insomnia, poor quality of sleep, and difficulties in maintaining restorative sleep. Additionally, cigarette smoking has also been highlighted as a risk factor in breathing sleep disorders (Zhang et al. 2006; Jaehne et al. 2015).

Numerous methods are available for assessing sleep quality and sleep-related disorders. Questionnaires are the most accessible and straightforward method for researchers, e.g. Pittsburgh Sleep Quality Index, Sleep Diaries, Epworth Sleepiness Scale. Questionnaires enable clinicians, researchers and patients to subjectively assess the quality and quantity of sleep (Landry et al. 2015). However, a questionnaire's reliability is dependent on respondents' memory and ability to recall events throughout the night. Alternatives to questionnaires include objective sleep testing methods, such as actigraphy, respiratory polygraphy and polysomnography (Tan et al. 2014; Landry et al. 2015). During these tests, sensors attached to a subject's body record information on overnight brain activity, blood oxygen saturation, breathing performance and limb activity, among others. Objective methods require use of professional equipment and participation of qualified personnel. However, such methods provide precise information about sleep parameters, architecture and patient activity during night, all of which are vital in diagnosing a range of sleep disorders. Among the objective sleep study methods, polysomnography is considered the gold standard method of sleep testing and provides the most significant information on sleep architecture (Littner et al. 2003). Sleep testing questionnaires have frequently been used to investigate the impact of smoking on sleep quality and excessive sleepiness during the day (Żarowski et al. 2007, Purani et al. 2019). However, similar analyses using polysomnography are much less common, particularly in Poland.

This study analyzes the impact of cigarette smoking on polysomnographic parameters of adult men. The dose effect of cigarette use was tested as a factor affecting the severity of breathing sleep disorders and sleep quality determinants.

Participants and methods

The materials for this study originated from the polysomnography laboratory hospital archives in Opolskie Province, Poland. The data included polysomnographic records for 94 men in the age range 38–60 years, all of whom were examined between 2015 and 2016.

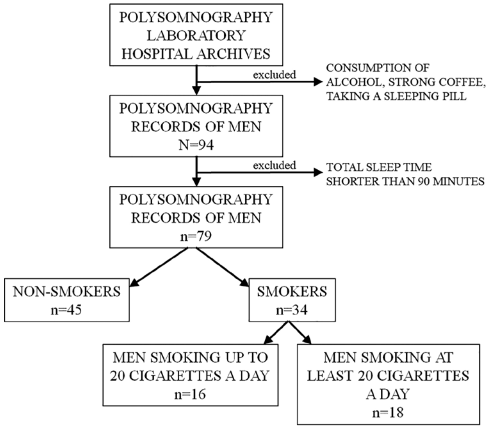

Fig. 1. Flowchart of exclusion criteria of the study

Consumption of alcohol, strong coffee or taking of sleeping pills the day before the test, was used as criterion for excluding individuals from the survey (Fig. 1). Following which, only records for male participants sleeping at least 90 minutes (one sleep cycle) were further analyzed. In total, 79 men met the criteria for inclusion in the study. Three groups of men were identified, based on their smoking habits: (1) non-smokers (n=45; 56.96%), (2) men smoking up to 20 cigarettes (a pack) a day (n=16; 20.25%; on average 13.56±4.9) and (3) men smoking more than 20 cigarettes a day (heavy smokers; n=18; 22.78%; on average 35.56±8.1).

The men were asked information on their height, body weight and co-morbidities. Relative body mass index (BMI, [kg/m^2]) was calculated. Systolic and diastolic blood pressure (mmHg) was checked during hospital admission. Obesity (BMI ≥ 30 kg/m^2), hypertension, diabetes type II and obstructive sleep apnea (categories based on apnea/hypopnea index (AHI): lack <5/h; low 5–14/h; medium 15–50/h; severe >50/h) were reported.

Polysomnography procedure

Polysomnography was conducted in the certified laboratory. Sleep recordings were conducted using Nox A1 PSG System (Nox Medical, Reykjavik, Iceland) equipment. This included electroencephalography (EEG), electrocardiography (ECG), electro-oculogram (EOG). Electroencephalography (EEG) electrodes were affixed to the head using a standard International 10–20 system with reference electrodes around the ears, on the chin and on the forehead. Oxygen saturation in the blood was controlled by a pulse oximeter, whilst snoring and sleep apnea episodes were controlled by a sensor placed next to the nose. Sensors on the chest, abdomen and limbs registered movements from those parts of the body and body position. The latter were recorded between 10 PM and 6 AM. Sensors were removed in the morning and polysomnography results were analyzed by a certified technician in accordance with laboratory regulations.

Sleep quality and architecture assessment

The following variables of sleep continuity and architecture were assessed:
- time in bed (TIB), defined as the time between turning the light off in the evening and turning the light on in the morning;
- total sleep time (TST), defined as the time between sleep onset and final awakening;
- total sleepless time, defined as the time spent awake during TIB;
- wake after sleep onset (WASO), defined as the time of wakefulness in the period between sleep onset and final awakening;
- sleep efficiency, time spent asleep to time spent in bed ratio (TST to TIB ratio);
- NREM sleep time, defined as the time spent in phases of non-REM sleep;
- REM sleep time, defined as the time spent in phases of REM sleep;
- NREM obstructive sleep apnea (NREM OSA), the total time of obstructive sleep apnea episodes during non-REM sleep phases;
- REM obstructive sleep apnea (REM OSA), the total time of obstructive sleep apnea episodes during REM sleep phases;
- obstructive sleep apnea in total (OSA), defined as the total time of obstructive sleep apnea episodes during TST;
- NREM sleep apnea index, the number of sleep apnea episodes in non-REM phases per hour of sleep;
- REM sleep apnea index, the number of sleep apnea episodes in REM phases per hour of sleep;
- sleep apnea index in total, the number of sleep apnea episodes in TST per hour of sleep;
- NREM apnea/hypopnea index (NREM AHI), defined as the number of NREM sleep apnea episodes and number of NREM sleep hypopnea episodes ratio per hour of sleep;
- REM apnea/hypopnea index (REM AHI), defined as the number of REM sleep apnea episodes and number of REM sleep hypopnea episodes ratio per hour of sleep;
- apnea/hypopnea index (AHI) in total, defined as the number of sleep apnea episodes and number of sleep hypopnea episodes ratio during TST per hour of sleep;
- NREM Oxygen Desaturation Index (NREM ODI), defined as the number

of blood oxygen desaturation in non-REM sleep stages per hour of NREM sleep;
- REM Oxygen Desaturation Index (REM ODI), defined as the number of blood oxygen desaturation in REM sleep stages per hour of REM sleep;
- Oxygen Desaturation Index (ODI) in total, defined as the number of blood oxygen desaturation per hour of sleep;
- Oxygen Desaturation Nadir in NREM sleep, defined as the lowest blood oxygen saturation a patient drops to during non-REM sleep;
- Oxygen Desaturation Nadir in REM sleep, defined as the lowest blood oxygen saturation a patient drops to during REM sleep;
- Oxygen Desaturation Nadir in total, defined as the lowest blood oxygen saturation a patient drops to during TST;
- isolated limb movement index, defined as number of isolated limb movements per hour of sleep;
- periodic limb movement index, defined as the number of periodic limb movements per hour of sleep;
- limb movement total index, defined as the number of all limb movements per hour of sleep;
- snoring index in total, defined as the number of snoring episodes per hour of sleep.

Statistical analysis

Polysomnographic parameters were analyzed using Statistica 13.3 Software. The data were checked for normality by employing the Shapiro-Wilk test. Because the normality was not present, data were analyzed using the Kruskal-Wallis test. Next, Tukey's HSD post-hoc tests were computed. Categorized variables were tested with a Chi-square (χ^2) test. All results were considered statistically significant at $p < 0.05$.

Results

Men smoking up to 20 cigarettes a day were significantly younger than non-smokers (H=10.16; p=0.006; Table 1; Fig. 2A).

Table 2 illustrates frequency of co-morbidities according to degree of smoking. The number of cigarettes smoked did not significantly affect the subject's health status of the subjects, except type II diabetes. A significantly higher incidence of type II diabetes (p=0.005) was recorded

Table 1. General characteristic of men by type of smoking habit – values of median and (Q1–Q3)

	Non-smokers (1)	Cigarette smoking: Smoking to 20 cigarettes daily (2)	Cigarette smoking: Smoking more than 20 cigarettes (3)	Kruskal-Wallis test value: H	Kruskal-Wallis test value: p
Age (years)	52.64 (47.71–57.98)	44.75 (41.26–49.76)	50.66 (45.85–55.77)	10.16	0.006
BMI (kg/m^2)	31.05 (28.72–35.14)	28.34 (25.30–35.39)	34.52 (31.24–38.72)	5.74	0.057
Systolic blood pressure (mmHg)	140 (130–150)	142.5 (135–150)	150 (130–150)	2.65	0.266
Diastolic blood pressure (mmHg)	80 (80–90)	90 (80–92.5)	80 (70–90)	3.55	0.170

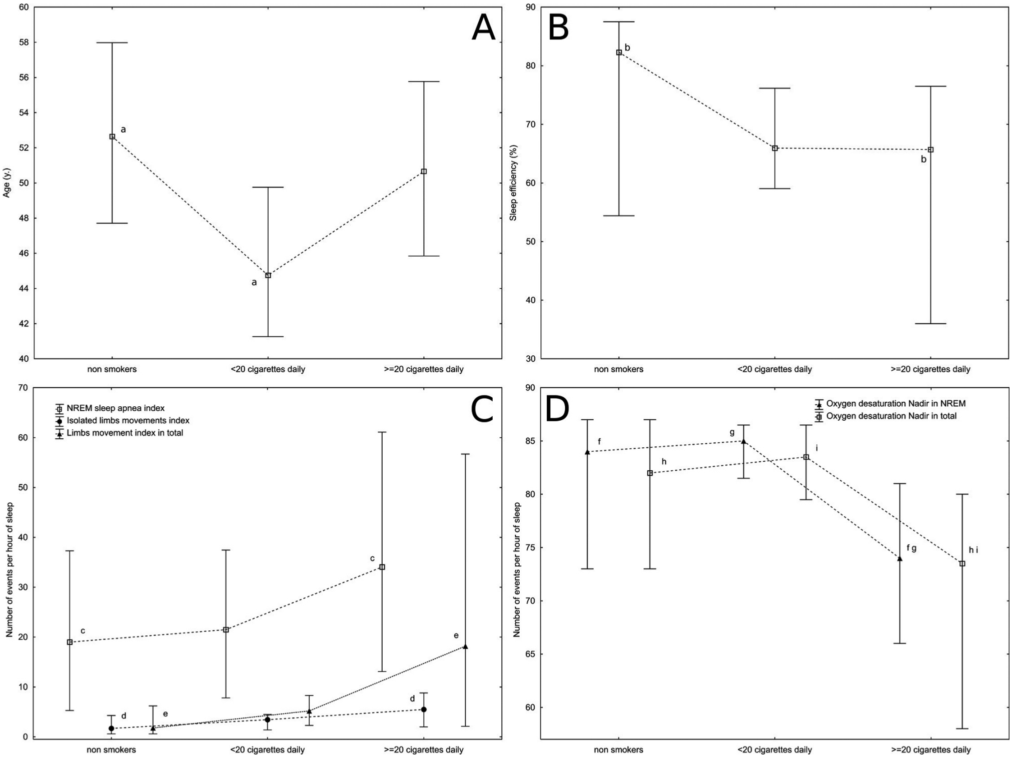

Fig. 2. Tukey's HSD post-hoc tests' results for statistically significant differences in three groups by smoking habit: A: age; B: sleep efficiency; C: number of events per hour of NREM sleep apnea, isolated limb movement and limb movement in total; D: oxygen desaturation Nadir NREM and in total. Significance levels: a. p=0.005; b. p=0.042; c. p=0.042; d. p=0.008; e. p=0.007; f. p=0.008; g. p=0.006; h. p=0.007; i. p=0.009

among men smoking more than 20 cigarettes a day, by contrast with men smoking less frequently and non-smokers. Among all three groups of men, heavy smokers more often, although not significantly, also suffered from obesity and hypertension.

Table 3 illustrates a comparison of the polysomnographic parameters of men with various smoking habits. Heavy smokers experienced 141.5 minutes (2 hours and 21.5 minutes) of sleeplessness, significantly longer than non-smokers (73 minutes–1 hour 13 minutes; H=8.11; p=0.017). Heavy smokers also recorded significantly more problems in terms of sleep continuity throughout the night (WASO), with time spent awake between falling asleep and final awakening, being the longest duration across the three groups (H=7.99; p=0.018). A comparison of these parameters indicates a reduction in sleep efficiency (TST to TIB ratio) being congruent with an increase in cigarettes smoked per day. Non-smokers slept the most efficiently, whilst heavy smokers slept the least efficiently (H=7.96; p=0.019; Figure 2B). Differences in NREM sleep time observed, although non-significant, indicated a shortening of the phase for the body resting, associated with an increase

Table 2. Frequency of co-morbidities in adult men with sleep disorders by cigarette smoking

Feature [%]	Cigarette smoking			χ^2 test significance level (*p*)
	Non-smokers	Smoking to 20 cigarettes daily	Smoking more than 20 cigarettes daily	
Obesity				0.058
Yes	55.56	37.50	77.78	
No	44.44	62.50	22.22	
Diabetes type II				0.005
Yes	4.44	0.00	27.78	
No	95.56	100.00	72.22	
Hypertension				0.453
Yes	44.44	43.75	61.11	
No	55.56	56.25	38.89	
Obstructive sleep apnea (OSA) degree				0.083
Lack	24.44	18.75	11.11	
Low	22.22	25.00	22.22	
Medium	46.67	43.75	27.78	
Severe	6.67	12.50	38.89	

Table 3. Sleep parameters of men by smoking habit – values of median and (Q1–Q3)

Feature	Cigarette smoking			Kruskal-Wallis test value	
	Non-smokers	Smoking to 20 cigarettes daily	Smoking more than 20 cigarettes daily	*H*	*p*
Time in bed (TIB) [min]	411 (379–426)	408.8 (397.3–434.5)	409.3 (366.5–424)	1.17	0.557
Total sleep time (TST) [min]	320 (223–354)	272.8 (233.8–326.5)	252.8 (151–310)	4.85	0.089
Total sleepless time [min]	73 (45.5–174.5)	141.5 (99.5–172.5)	141.5 (86–264)	8.11	0.017
Wake time After Sleep Onset (WASO) [min]	59.5 (38.5–165.5)	129 (85.5–163.8)	133.5 (76.5–256)	7.99	0.018
Sleep efficiency (TST to TIB ratio)	82.3 (54.4–87.5)	66 (59.1–76.2)	65.7 (36–76.5)	7.96	0.019
NREM sleep time [min]	283.5 (201.5–320)	225.5 (199–246.3)	236.8 (134.5–284.5)	4.92	0.086
REM sleep time [min]	18.5 (6–42.5)	13.8 (2–89.8)	14.5 (3.5–36)	0.32	0.852
NREM obstructive sleep apnea [min]	48 (18–130)	67 (22–136)	78 (46–266)	3.55	0.169
REM obstructive sleep apnea [min]	3 (0–9)	3.5 (0–10.5)	5.5 (0–18)	0.50	0.780
Obstructive sleep apnea in total [min]	55 (24–149)	76.5 (25.5–143)	79 (60–296)	2.93	0.231
NREM sleep apnea index (events per hour)	19 (5.3–37.3)	21.5 (7.8–37.5)	34.1 (13.1–61.1)	6.23	0.045
REM sleep apnea index (events per hour)	12.6 (0–27.5)	9.1 (0–26)	26.8 (0–34.3)	1.27	0.530

Feature	Cigarette smoking			Kruskal-Wallis test value	
	Non-smokers	Smoking to 20 cigarettes daily	Smoking more than 20 cigarettes daily	*H*	*p*
Sleep apnea index in total (events per hour)	17.3 (5.3–37.9)	21.1 (7.5–37.2)	29 (13.9–57.3)	5.28	0.071
NREM apnea/hypopnea index	19 (5.3–37.9)	21.6 (7.8–39.3)	34.1 (13.1–61.1)	6.21	0.045
REM apnea/hypopnea index	12.6 (0–27.5)	9.1 (0–26)	26.8 (0–34.3)	1.23	0.540
Apnea/hypopnea index in total	17.3 (5.3–37.9)	21.2 (7.5–39.1)	29 (13.9–57.6)	3.68	0.159
NREM Oxygen Desaturation Index (NREM ODI)	28.8 (9.6–63.3)	34.8 (8.6–62)	56.7 (28.3–99.3)	5.44	0.066
REM Oxygen Desaturation Index (REM ODI)	23.4 (4.2–50)	18.2 (3.7–33.3)	47.6 (14.3–88.9)	5.21	0.074
Oxygen Desaturation Index in total (ODI)	26.5 (8.8–63.1)	33.7 (8.3–61.6)	49.8 (22.6–95.8)	4.78	0.092
Oxygen Desaturation Nadir in NREM	84 (73–87)	85 (81.5–86.5)	74 (66–81)	11.76	0.003
Oxygen Desaturation Nadir in REM	79 (0–87)	83 (0–88.5)	74.5 (0–83)	1.19	0.553
Oxygen Desaturation Nadir in total	82 (73–87)	83.5 (79.5–86.5)	73.5 (58–80)	11.44	0.003
Isolated limb movement index	1.7 (0.6–4.3)	3.5 (1.4–4.5)	5.5 (2–8.8)	9.25	0.010
Periodic limb movement index	0.2 (0–0.4)	0.4 (0–0.8)	0.4 (0–0.5)	8.27	0.016
Limb movement index in total	1.8 (0.6–6.2)	5.2 (2.3–8.3)	18.2 (2.1–56.7)	9.81	0.007
Snoring index in total	60.3 (4.7–171)	38.6 (4.7–127.8)	114 (47.9–223.3)	4.09	0.129

in smoking intensity. Since the analysed groups differed significantly in age, and age was a factor influencing sleep length, the relationship between sleep length and age was examined. The tests did not show any statisitically significant relationship between age and sleep duration, sleepless time, WASO or sleep efficiency in investigated men (data not shown). We may infer from this that differences in sleep parameters may stem from cigarette use and not from age differences in examined group.

Analyses of parameters regarding apnea and hypopnea (AHI) indicated that heavy smokers experienced more respiratory disturbances during both NREM and REM sleep. In this regard, breaks in breathing were more numerous and lasted longer in smokers: men smoking more than 20 cigarettes a day displayed the worst results, albeit, only in NREM sleep apnea index (H=6.23; p=0.045; Figure 2C) and NREM apnea/hypopnea index (H=6.21; p=0.045), differences were statistically significant. Oxygen Desaturation Nadir in the group of men smoking more than 20 cigarettes a day in NREM sleep, was statistically the lowest out of the three groups (H=11.76; p=0.003; Figure 2D). Limb movements per hour of sleep were significantly more frequent among men who smoked more (H=9.81; p=0.007; Figure 2C), the highest number of movements being among heavy smokers. Snoring was also most common in men smoking more than 20 cigarettes a day, although not significantly.

Discussion

A key finding of the study was in identifying the dose effect of cigarette smoking on sleep parameters, which found that smokers, in contrast with non-smokers, had significantly worse objective sleep quality. These findings were consistent with results of other studies (Jaehne et al. 2012; Liao et al. 2019) and support the thesis that cigarettes have a negative impact on quality of sleep (Wetter and Young 1994; Cohrs et al. 2014).

Numerous sleep quality assessment methods exist and can be categorized as following either the subjective or an objective approach. Subjective methods, such as self-reported sleep diaries or questionnaires, are time and cost-efficient, relatively easy to use, and are broadly selected for sleep quality studies (Wetter 1994; Cohrs et al. 2014; Bellatorre et al. 2017; Liao et al. 2019; Purani et al. 2019). However, results of subjective studies rely solely on patients' memory and their ability to assess sleep quality. This approach lacks information on specific parameters, such as length and architecture of sleep phases, and occurrence and length of disordered events during the night, aspects which objective sleep studies are more suitable to analyse. As Landry et al. (2015) demonstrate, perceived quality of sleep significantly differs from the objective one. Polysomnography represents the gold-standard in objective sleep study. It enables researchers to collect information on brain and limb activity, breathing performance, oxygen blood levels during night rest and many more sleep parameters (Tan et al. 2014). While polysomnography provides more detailed and varied information about sleep patterns, it's more time-consuming, requires more expensive equipment and qualified personnel than subjective methods, hence its less frequent application in sleep studies (Tan et al. 2014; Landry et al. 2015). In medical practice, polysomnography is the basic method for diagnosing, implementing and evaluating treatment of sleep disorders (Lim et al. 2020). As a result of numerous studies linking altered sleep quality with obesity, alcohol and caffeine use or cigarette smoking, determining the risk factors associated with sleep disorders has become possible, improving the treatment of sleep disorders (Kashyap et al. 2001; Young et al. 2004; Zhang et al. 2006; Hsu et al. 2019; Spadola et al. 2019).

In this study, polysomnographic parameters indicated that heavy smokers' quality of sleep was significantly worse in comparison with other men. The American Academy of Sleep Medicine and Sleep Research Society, established 7–9 hours of sleep as optimal to support healthy living in adults (Watson et al. 2015). Overall, the total sleep time for study subjects was shorter than recommended by the American Academy of Sleep Medicine. Out of the three groups involved in the study, heavy smokers slept the least and non-smokers slept the most. Similarly, the more cigarettes men smoked in a day, the less they slept during the night, as well as waking more frequently (WASO), resulting in a significantly lower overall sleep efficiency. Sleep efficiency in non-smokers stood at 82.3% compared to 65.7% in heavy smokers. These findings are consistent with results from other studies (Zhang et al. 2006; Jaehne et al. 2012; Hsu et al. 2019; Liao et al. 2019) that found smokers had less total sleep time, more sleepless time and more WASO time, compared with non-smokers. Additionally, transdermal nicotine delivery during the night had a similar effect in subjects' sleep quality, resulting in a reduction in patients' total sleep time and sleep efficiency (Davila et al. 1994).

Obstructive sleep apnea (OSA), which is based on the number of apnea (complete airflow cessation) and hypopnea (reduced airflow) episodes per hour of sleep (Qaseem et al. 2013), is the most common sleep-related breathing disorder. To diagnose OSA of mild degree, occurrence of five respiratory events per hour of sleep is sufficient. The degree of OSA that was based on the value of the apnea/hypopnea index, did not significantly differ across the three groups. However, this trend showed a correlation between increasing cigarettes smoked per day and greater severity in OSA prevalence. Likewise, it was noted that smokers displayed greater susceptibility of respiratory disturbances' during sleep than did non-smokers, as noted across numerous other studies (Wetter et al. 1994; Kashyap et al. 2001; Kim et al. 2012; Tzischinsky et al. 2012; Hsu et al. 2019). However, according to Hoffstein et al. (2002), when adjusted for other variables, smoking alone was not significantly related to AHI values. The findings indicate that smokers are more predisposed to experiencing breathing problems during sleep. Apneas and hypopneas cause hypoxia that often results in waking, thereby, impairing a patient's ability to reach phases of deep, most restful, sleep (McNicholas et al. 2002). The trend in the current study identifies that men who smoked more, spent less time in deep sleep, resulting in less efficient recovery of the body during sleep.

Another measure of poor sleep quality is Oxygen Desaturation Index (ODI). This measure indicates how many times the oxygen concentration in blood has dropped during sleeping hours. Such a drop may be due to respiratory disturbances, like apnea or hypopnea, leading to a reduction of oxygen supply to the lungs and a consequent reduction of oxygen concentration in the blood. In the current study, the number of oxygen desaturation episodes per hour (ODI) were most numerous in heavy smokers. Corresponding trends had been previously identified by Conway et al. (2008), who stated that higher ODI is associated with smoking. Kim et al. (2012) found ODI in heavy smokers to be much higher than in mild and non-smokers, but registered no significant difference between non-smokers and smokers alone, when the dose effect had not been considered. Similarly, significant differences in ODI were not found between smoker and non-smoker groups, however, nocturnal oxygen saturation decreases were notable in smokers by contrast with non-smokers (Hsu et al. 2019). Consistent with Hsu et al.'s (2019) results, Oxygen Desaturation Nadir in heavy smokers in NREM sleep, as well as in sleep time in total, was significantly lower than in other groups. This relationship may result from the high number of breathing disturbances in heavy smokers. Such disturbances impair oxygen delivery during sleep leading to a drop in oxygen levels in the blood.

The frequency of limb movements per hour of sleep was significantly higher in heavy smokers, where the dose effect of smoking on limb movements was observed. Such a finding is consistent with Jaehne et al. (2012), who found greater prevalence of leg movements per hour of sleep in smokers by contrast with non-smokers. Additionally, Restless Leg Syndrome (RLS) was associated with smoking more than 20 cigarettes a day (Ohayon and Roth 2002). However, transdermal nicotine distribution did not significantly affect periodic leg movements per hour (Davila et al. 1994). Additionally, no differences in snoring frequency resulted between groups who obtained nicotine and those provided with a placebo (Davila et al. 1994). By contrast, in this study snoring was linked to heavy smoking as also noted in Hsu et al.'s (2019) study.

It has been suggested that nicotine intake can be contribute to abnormal sleep architecture and deficits in initiating and maintaining sleep continuity in smokers (Davila et al. 1994). Nicotine, the primary active substance in cigarette smoke, acts as a stimulant on the nervous system (Zhang et al. 2006), thereby raising alertness, causing increased sleep latency and heightened wakefulness following the onset of sleep. Additionally, cigarette smoke disrupts genes responsible for controlling circadian rhythms (Hwang et al. 2014). Smoking also predisposes smokers to snoring and obstructive sleep apnea symptoms. During the night, smokers can also experience sleep problems connected to night withdrawal of nicotine (Liao et al. 2019).

There were a few limitations in this study, beyond limitations in the selection of participants. In this regard, the analyses covered subjects who applied for polysomnographic examinations, due to sleep problems. Therefore, the observed frequency of disturbances was overestimated by comparison with population data. However, the study demonstrates the clear influence of smoking on the observed parameters of sleep quality. Therefore, it can be speculated that eliminating smoking from an individual's lifestyle may significantly improve the sleep quality in people with sleep disorders. There were also significant differences in ages between the selected groups. Non-smokers were among the eldest in the sample in contrast with those who smoked more or less than 20 cigarettes a day. However, given that age, regardless of other factors, significantly affects the quality of sleep (older people tend to have a poorer quality of sleep than younger people (Zeitlhofer et al. 2000), older non-smokers in this study had a better quality of sleep than younger smokers. Finally, never smokers and ex-smokers were not distinguished among non-smokers. Although, non-smokers had the fewest sleep problems, it cannot be excluded that at least some of the sleep problems in this group of respondents may have been due to the fact of quitting smoking.

Conclusions

Those men that smoked more than 20 cigarettes a day also displayed the greatest amount of sleeplessness, recorded more wake time after sleep onset, as well as the lowest sleep efficiency in contrast with non-smokers and mild smokers. Additionally, heavy smokers had significantly more apnea events per hour of sleep, the lowest Oxygen Level Nadir and the highest rate of limb movements per hour of sleep. Moreover, in contrast with Zhang et al.'s (2006) study and Liao et al.'s (2019) study, the dose effect of daily cigarette consumption on sleep parameters indicated that the more men smoked, the poorer was their sleep quality. Further studies that broaden the scope of this study are essential, particularly for exploring specific factors in cigarette smoke alone to determine their impact on the quality of sleep. Future research should also involve a sample of healthy adults, rather than solely hospital patients.

Authors' contribution

AW conceived and designed the analysis, researched literature, collected the data, performed the analysis, wrote the paper. AML conceived and designed the analysis, researched literature, wrote the paper and supervised.

Conflict of interest

The authors declare no conflict of interests.

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