Egyptian Journal of Chest Diseases and Tuberculosis (2012) **61**, 459–468

The Egyptian Society of Chest Diseases and Tuberculosis

Egyptian Journal of Chest Diseases and Tuberculosis

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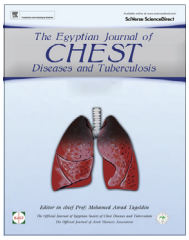

ORIGINAL ARTICLE

The use of overnight pulse oximetry and phoniatrics parameters in the screening protocol of obstructive sleep apnea

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Received 13 July 2012; accepted 22 August 2012
Available online 26 January 2013

KEYWORDS

Obstructive sleep apnea–hypopnea syndrome;
Pulse oximetry;
Acoustic analysis of voice

Abstract *Background:* Obstructive sleep apnea–hypopnea syndrome (OSAHS) is a major public health problem due to its high prevalence rate. Polysomnography is the current golden standard test for diagnosis of OSAHS. The studies with pulse oximetry reveal a high sensitivity and suggest that as a screening tool, these may exclude some patients with negative studies from further work-up for OSAHS. Acoustic analysis of snoring sounds would offer the advantage of a non-invasive technique that would be used to monitor normal sleep. The posterior vocal tract resonances (i.e. F1 and F2) of OSA patients would yield lower frequency values compared to non-OSA individuals.

Objective: To determine the sensitivity and specificity of overnight oximetry and phoniatrics parameters in evaluation of OSAHS and to compare the results with those obtained from polysomnography (PSG) as the gold standard test.

Patients and methods: Twenty patients, were presented with presumptive clinical diagnosis of OSAHS, each patient was subjected to: Full history taking: including age, sex, complain and Epworth Sleepiness Scale (ESS). Systemic examination: Including general examination and body mass index (BMI). Standard ENT examination and fibroptic pharyngoscopy with Müller maneuver. Polysomnography was done using RESMED Apnea Link screening device. Other tests: Acoustic analysis of voice and acoustic analysis of snoring sounds using computerized speech lab (CSL). Pulse oximetry: The overnight oximetry was analyzed using the Wrist Pulse Oximeter MD300W.

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Peer review under responsibility of The Egyptian Society of Chest Diseases and Tuberculosis.

ELSEVIER Production and hosting by Elsevier

 http://dx.doi.org/10.1016/j.ejcdt.2012.08.017

Results: Eighteen patients (90%) were found to have OSAHS and two patients (10%) were simple snorers. The sensitivity of overnight pulse oximetry for an apnea hypopnea index of >5, >15, and >30/h was 66.7%, 80%, and 100% respectively and the specificity was 50%. The formant frequencies of different vowels (i, u and a) in OSA patients and non-OSA snorers revealed that the mean F1 value for the vowel /i/ was significantly lowered in OSA patients. In addition, the mean F2 value of the vowel /i/ and /u/ was markedly lowered in OSA patients. There was significant increase in values of bandwidths (BW1 and BW2) for /i/ and /u/ vowels in OSA patients in comparison to non-OSA snorers.

Acoustic analysis of snoring sounds revealed that; in the palatal snorers group, the average pitch was 105 ± 8 Hz and in the tongue base snorers group the average pitch was 263 ± 17 Hz; meanwhile the average pitch in the combined group was 160 ± 14 Hz. The difference was highly significant between the 3 groups. However harmonic to noise ratio was increased in patients with tongue base obstruction.

Conclusions: Polysomnography is the current golden standard test for diagnosis and evaluation of degree of OSA. Overnight pulse oximetry offers an inexpensive method of screening for and diagnosing OSAHS. Oximetry alone allowed confident recognition of moderate and severe cases of OSAHS. Acoustic analysis of snoring sounds and voice in patients with snoring and/or OSAHS is useful as a screening or supportive method with other investigations to diagnose the site of upper airway obstruction during sleep.

Introduction

Obstructive sleep apnea–hypopnea syndrome (OSAHS) is a major public health problem due to its high prevalence rate, increased morbidity and mortality, and increased public safety risk [1].

OSAHS is defined by five or more respiratory events (apneas and hypopneas) in association with excessive daytime somnolence, waking with gasping, choking, or breath-holding, or witnessed reports of apneas, loud snoring, or both [2].

The definitive study to evaluate OSAHS is overnight polysomnography (PSG) [3]. Polysomnography is the current golden standard test for diagnosis and evaluation of degree of OSAHS. It is used to differentiate between simple snoring and OSAHS and to determine the presence, type and severity of any apneic or hypopneic episodes [4].

Monitoring of overnight oxygen saturation has been considered to be reliable in detecting patients with OSAHS [5]. The studies with pulse oximetry reveal a high sensitivity and suggest that as a screening tool, these may exclude some patients with negative studies from further work-up for OSAHS [6].

In the last few years, debate has centered on the effectiveness of overnight pulse oximetry as a screening tool to identify patients with sleep-disordered breathing from patients with simple snoring and those with excessive daytime sleepiness from other causes [7–9]. This controversial discussion has arisen from needs to reduce the cost for diagnostic procedures in sleep disorders while technologic advances have made pulse oximeters handier, cheaper, and more reliable [10,11].

Examining the vocal tract resonances of individuals with OSA may prove to be diagnostically useful for two reasons. First, cephalometric research has indicated that the distance from the hyoid bone to the mandibular plane is significantly longer for patients with OSA compared to non-OSA individuals. This finding suggests that the vocal tract of OSA individuals is longer compared to non-OSA individuals. Accordingly, acoustic theory would predict that the posterior vocal tract resonances (i.e. F1 and F2) of OSA patients would yield lower frequency values compared to non-OSA individuals. Thus a reasonable hypothesis is that the formant frequencies of OSA patients should be significantly lower compared to non-OSA individuals owing to differences in vocal tract length. A second reason for examining vocal tract resonance in OSA patients relates to the damping characteristics of the vocal tract. A common finding among OSA patients is an increase in both velar and pharyngeal compliance. The increase in tissue compliance of these structures would be expected to alter vocal tract elasticity. In the case of vowel production, excessive tissue compliance would tend to increase the sound damping within the vocal tract. Therefore, measurement of formants bandwidths would help to evaluate vocal tract compliance. Formant bandwidth provides an estimate of sound damping within the vocal tract, as well as the rate of sound energy absorption. Considerable vocal tract compliance and sound damping translates to a wide formant bandwidth. Thus, a second hypothesis to consider is that the formant bandwidths characterizing the voices of OSA subjects should be significantly wider compared to non-OSA individuals because of differences of vocal tract damping [12].

Aim of the work

The aim of the study was to determine the sensitivity and specificity of overnight oximetry and phoniatrics parameters in evaluation of OSAHS and to compare the results with those obtained from polysomnography as the gold standard test.

Patients and methods

The study was conducted on twenty patients, presenting with presumptive clinical diagnosis of OSAHS, attending the outpatient clinic of the chest and Otolaryngology – Head & Neck Surgery Departments, Main University Hospital. Prior to conduction of the study, informed detailed consent was taken from every patient.

Each patient was subjected to:

1. *Full history taking:* including age, sex, complain and Epworth Sleepiness Scale (ESS).
2. *Systemic examination:* including general examination and body mass index (BMI).
3. *Standard ENT examination:* including nose, oral cavity and oropharynx. The amount of airway obstruction at the oropharyngeal level was graded according to Mallampati score [13].
4. Endoscopic examination using fibroptic pharyngoscopy with Müller maneuver [14].
5. *Polysomnography:* Polysomnography was the golden standard test for diagnosis and evaluation of degree of OSAHS. Polysomnography was done using RESMED Apnea Link screening device for sleep apnea, from RESMED Corporation (Fig. 1).
6. Other tests:

Acoustic analysis of voice

The voice of each patient was subjected to acoustic analysis using computerized speech lab (CSL) model 4300 from Kay Elemetrics (Fig. 2). The patient was seated in front of the microphone and the mouth-microphone distance was about 10 cm. The patient was asked to produce sustained vowel /a/ in a flat tone at a comfortable pitch and at constant amplitude.

Formant frequencies were done for the vowels (a, i and u), the first 2 formants (F1 and F2) and the first 2 bandwidths (BW1 and BW2) were tested for these vowels.

Acoustic analysis of snoring sounds

Snoring sound of each patient was recorded in the sleep laboratory using a digital recorder for several minutes. The microphone was fixed 3 cm from the mouth of the patient during sleep. The recorder snoring sample was subjected to acoustic analysis using CSL model 4300. The loudest snoring sound during inspiration was analyzed.

For each snoring sample, the following parameters were measured and studied: The waveform patterns of snoring sounds were studied for the frequency duration and the frequency range, average pitch, Jitter, Shimmer, Harmonic to noise ratio, and the first 2 formants (F1and F2) and the first 2 bandwidth (BW1 and BW2) for the vowels (a, i, u).

Figure 2 Computerized speech lab (CSL) model 4300 from Kay Elemetrics.

Pulse oximetry

The overnight oximetry was analyzed using the Wrist Pulse Oximeter MD300W From Beijing Choice Electronic Technology Co., Ltd. (Fig. 3).

The MD300W wrist oximeter is a portable non-invasive device which checks oxygen saturation of arterial hemoglobin (SpO_2) and pulse rate of adult and pediatric patient at home, and hospital. The MD300W wrist oximeter has the advantage of continuous recording of oxygen saturation and pulse rate during sleep. These data are then transferred to the computer where they are analyzed using special software. A graphic display of oxygen saturation against time and pulse rate against time is obtained. An oxygen desaturation is defined as a decrease of $\geqslant 4\%$ from baseline SaO_2 (Figs. 4–8).

Three typical patterns were defined:

1. Positive for sleep apnea: cyclical change with significant desaturation.
2. Negative for sleep apnea: steady tracing with little variation throughout sleep.
3. Uninterpretable or technically unsatisfactory: where no satisfactory graph can be obtained such as in cases where the oximeter probe has been disconnected throughout the night.

Figure 1 Polysomnography apparatus connected to the patient.

Figure 3 The Wrist Pulse Oximeter MD300W.

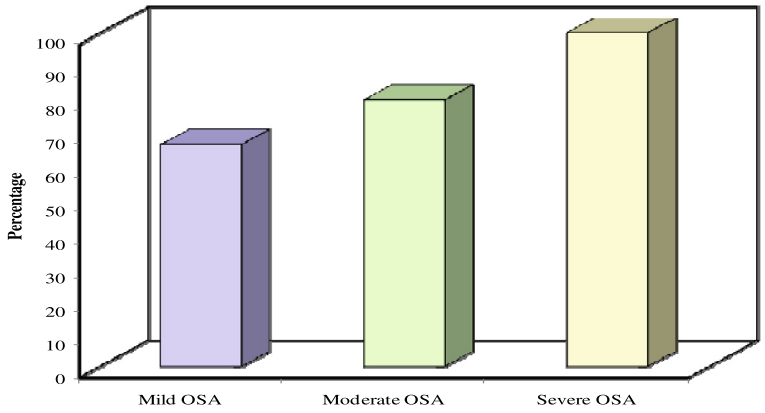

Figure 4 Sensitivity of overnight pulse oximetry in different degrees of OSA.

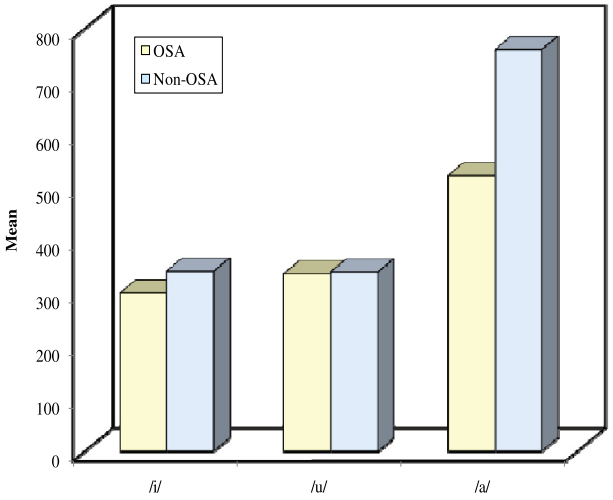

Figure 5 Average first formant (F1) values for the vowels /i/, /u/ and /a/ produced by the groups of OSA patients and non-OSA snorers.

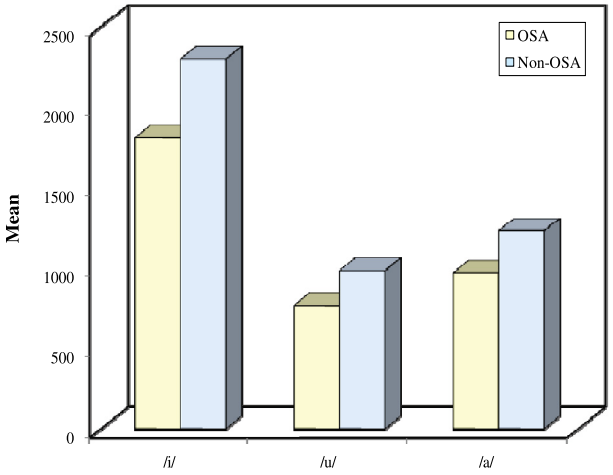

Figure 6 Average second formant (F2) values for the vowels /i/, /u/ and /a/ produced by the groups of OSA patients and non-OSA snorers.

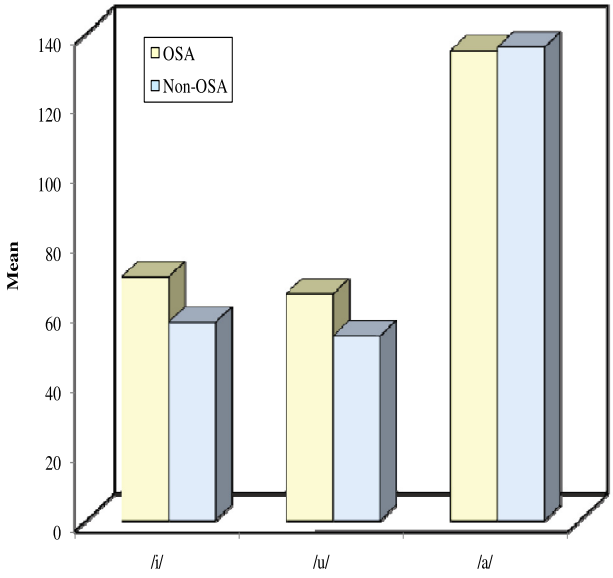

Figure 7 Average BW1 values for the vowels /i/, /u/ and /a/ produced by OSA patients and non-OSA snorers.

Results

Twenty patients, presenting with presumptive clinical diagnosis of OSAHS were included in this study. The main complain was snoring (Table 1). The age of all patients ranged from 21 years to 61 years with the mean age of 42.21 ± 10.53 years. There were 11 male patients representing (55%) and 9 female patients representing (45%) of the study population. The main complain of the patients was loud habitual snoring in 20 patients (100%).

Epworth Sleepiness Scale (ESS) was applied for all patients. ESS ranged from 10 to 20 with the mean of 14.05 ± 2.7, BMI ranged from 26.4 to 32.9 kg/m^2 with the mean of 29.99 ± 2.1 kg/m^2.

Standard ENT examination

A standard ENT examination was done for all patients. Four patients (20%) had nasal problems, two patients had deviated septum and two patients had hypertrophied inferior turbinate.

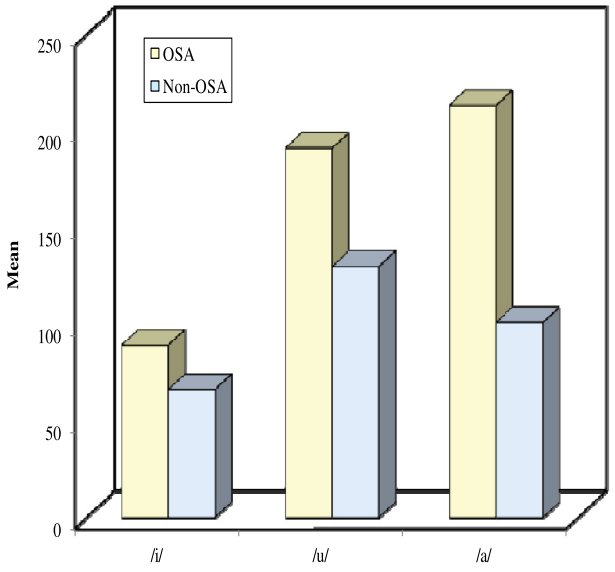

Figure 8 Average BW2 values for the vowels /i/, /u/ and /a/ produced by OSA patients and non-OSA snorers.

Table 1 Distribution of studied cases according to complain.

Complain	No.	%
Loud habitual snoring	20	100.0
Excessive daytime sleepiness	18	90.0
Witnessed apneas	13	65.0
Frequent arousals	12	60.0
Morning headache	12	60.0
Impaired intellectual function	3	15.0
Dry mouth or throat in the morning	5	25.0

By oropharyngeal examination using tongue depressor and laryngeal mirror, nine (45%) patients were found to have tonsillar hypertrophy, four patients (20%) had elongated uvula, three patients (15%) had narrow palatal arches, three patients (15%) had enlarged uvula, and twelve patients (60%) had enlarged tongue dorsum with difficulty to visualize the larynx (Table 2). The Mallampati score was graded for all patients. Twelve patients (60%) were Mallampati class 3, four patients (20%) were class 4 and four patients (20%) were class 2.

Fibroptic pharyngoscopy with Müller maneuver

The Müller maneuver was done for all patients to assess collapse of the retropalatal and retroglossal areas during inspiration against a closed nose and mouth (Table 3).

Table 2 Distribution of studied cases according to ENT examination findings.

ENT examination	No.	%
Nasal problem	4	20.0
Palatal abnormality	10	50.0
Tonsillar hypertrophy	9	45.0
Enlarged tongue dorsum	12	60.0

Polysomnography

In Table 4 eighteen patients (90%) were found to have OSAHS and two patients (10%) were simple snorers. Ten patients (50%) had severe OSAHS, five patients (25%) had moderate OSAHS and three patients (15%) had mild OSAHS.

Pulse oximetry

The information from the definitive sleep study (polysomnography) was used to determine the sensitivity and specificity of the overnight pulse oximetry in detecting OSAHS. The sensitivity of overnight pulse oximetry alone for the recognition of OSAHS was calculated as the number of true positive SaO_2 records divided by the total number of positive definitive (polysomnographic) records-that is, true positive plus false negative SaO_2 records. Specificity was defined as the number of the true negative SaO_2 records divided by the total number of negative definitive records-that is, true negative plus false positive SaO_2 records. In the assessment of the sensitivity and specificity of the overnight oximetry recording "uninterpretable" traces were regarded as negative. The sensitivity and specificity of overnight pulse oximetry for detection of OSAHS were determined for apnoea-hypopnoea indices exceeding 5, 15, and 30 events an hour (mild, moderate and severe OSAHS). (Tables 5–8)

Acoustic analysis of snoring sounds

In our study, we found the average pitch of snoring sounds of patients in palatal snoring was 105 ± 8 Hz. The average pitch of tongue base snoring was 263 ± 17 Hz. The average pitch of combined (palatal and tongue base) snoring was 160 ± 14 Hz. The difference was logically highly significant between the 3 groups. Also we found increased harmonic to noise ratio (H/N) in patients with tongue base obstruction.

Acoustic analysis of voice

In Table 9 there was significant decrease in F1 values for /i/ vowel in OSA patients in comparison to non-OSA snorers. While in Table 10 we found significant decrease in F2 values for /i/ and /u/ vowel in OSA patients in comparison to non-OSA snorers.

There was significant increase in BW1 and BW2 values for /i/ and /u/ vowels in OSA patients in comparison to non-OSA snorers (Tables 11 and 12).

Discussion

Obstructive sleep apnea (OSA) is a sleep disorder that involves cessation or significant decrease in airflow in the presence of breathing effort. It is the most common type of sleep-disordered breathing (SDB) and is characterized by recurrent episodes of upper airway collapse during sleep. These episodes are associated with recurrent oxyhemoglobin desaturations and arousals from sleep [15].

Traditionally, polysomnography has been the gold standard for the diagnosis of OSAHS [16]. Full polysomnography requires admission to a sleep laboratory and it is expensive and time consuming, and the equipment and the expertise to run it

Table 3 Distribution of studied cases according to findings of Müller maneuver.

Findings of Müller maneuver	No.	%
Patients with pharyngeal collapse mainly at velopharyngeal valve (palatal group)	7	35.0
Patients with pharyngeal collapse mainly at base of tongue (tongue base group)	5	25.0
Patients with pharyngeal collapse at velopharyngeal valve and base of tongue (combined group)	8	40.0

Table 4 Distribution of studied cases according to Polysomnography findings.

Positive			Negative
Mild	Moderate	Severe	2 (10%)
AHI 5–15	AHI 15–30	AHI > 30	
3 (15%)	5 (25%)	10 (50%)	

Table 5 Descriptive analysis of studied cases according to respiratory events occurring during sleep on room air.

Respiratory events occurring during sleep	Range	Mean ± SD	Median
Total events	12.0–594.0	187.70 ± 168.84	128.0
Total apneas	0.0–347.0	59.05 ± 85.91	29.0
Total hypopneas	12.0–300.0	128.65 ± 98.22	95.50
AHI	3.0–97.0	43.90 ± 28.69	42.0
No of desaturations	5.0–231.0	59.45 ± 69.93	30.0
ODI 4%	1.0–59.0	10.65 ± 13.04	8.50
Aver. SpO_2 %	86.0–97.0	95.10 ± 2.53	96.0
Minimal SpO_2 %	68.0–94.0	83.20 ± 7.47	82.0
T90 min	0.0–240.0	21.95 ± 53.10	7.50
Snoring episodes	30.0–4442.0	665.0 ± 1161.57	155.50

is not widely available. The advent of overnight pulse oximetry offers an inexpensive method of screening for and diagnosing OSAHS. It is less likely to disturb sleep and uses robust biological parameters of oxygen saturation and pulse rate. [17]

In this study, the sensitivity of overnight pulse oximetry for an apnea hypopnea index of > 5, > 15, and > 30/h was 66.7%, 80%, and 100% respectively and the specificity was 50%. Oximetry alone therefore allowed recognition of a moderate or severe sleep apnea syndrome.

Pépin et al. [18] used a mathematical index to detect changes in SaO_2 associated with sleep apneas with a sensitivity of 75% and a specificity of 86%.

Williams et al. [8] used a visual analysis of oximeter tracings without taking into account desaturations of ⩾4% when they occurred at levels of saturation above 90%. They obtained a sensitivity of 75% and a specificity of 100% in a small number of patients.

Sériès et al. [5] used oximetry as a diagnostic tool but the high numbers of false positives negated its use as a case selection tool for detecting OSA in suspected patients. They did not define desaturations with a fixed numerical criterion, counting as abnormal patients who had more than 10 transient desaturations per hour followed by a rapid return to the baseline level. Moreover, they did not show pulmonary function data in patients with normal polysomnography and more than 10 desaturations per hour.

Epstein et al. [19] compared the cost of nocturnal oximetry as a case selection tool with the cost of standard PSG for the detection of OSA. They concluded that the use of overnight oximetry as a diagnostic tool was limited because of the high rate of false positive results. They concluded that the use of overnight oximetry as a case selection tool is not justified on the basis of cost effectiveness but they gave no explanation for the high number of false positives.

Chiner et al. [20] have looked at the validity of overnight oximetry as a screening device, comparing full PSG with overnight oximetry in 275 patients with suspected OSA. For overnight oximetry the authors defined a significant oxygen desaturation as any fall in oxygen of ⩾4% below baseline values during a six second period and derived an oxygen desaturation index (ODI) as the total number of desaturations during the night divided by the total number of hours in bed. Using ODI values of > 5, > 10, and > 15 they diagnosed 192, 160, and 139 patients, respectively, as having OSA of whom 14, 6, and 4 subjects, respectively, were false positives when assessed by PSG. These results gave sensitivity and specificity values ranging from 62% to 93% and positive predictive values of 92% to 96%. For the group of patients with ODI values of > 5 the 14 false positive patients all had intercurrent diagnoses including chronic obstructive pulmonary disease (COPD), obesity hypoventilation, ischaemic heart disease, and myotonia dystrophica and had significantly lower spirometric values than the true positive population. Using ODI value of > 5 the authors estimate that they would have reduced the number of PSGs performed in their unit by approximately 50%.

From these studies we conclude that there are wide variations between various studies as regard the criteria used to

Table 6 Pulse oximetry.

Polysomnography			Oximetry records				Sensitivity of oximetry (TP/TP + FN)%	Specificity of oximetry (TN/TN + FP)%
Degree of OSA	Positive	Negative	TP	FN	TN	FP		
Mild	3	2	2	1	1	1	66.7	50.0
Moderate	5		4	1			80.0	
Severe	10		10	0			100.0	

TP – true positive; FN – false negative; TN – true negative; FP – false positive.

Table 7 Comparison between acoustic analysis of snoring sounds in the 3 groups by using *t*-test.

	Palatal group Mean ± SD	Tongue base group Mean ± SD	Palatal group Mean ± SD	Combined group Mean ± SD	Tongue base group Mean ± SD	Combined group Mean ± SD
Average pitch (Hz)	105 ± 8 Hz	263 ± 17 Hz	105 ± 8 Hz	160 ± 14 Hz	263 ± 17 Hz	160 ± 14 Hz
P Value	< 0.001		< 0.001		< 0.001	
Sig.	HS		HS		HS	
Jitter (%)	2.8 ± 1%	2.7 ± 0.7%	2.8 ± 1%	2.82 ± 1	2.79 ± 0.7%	2.82 ± 1
P Value	> 0.05		> 0.05		> 0.05	
Sig.	NS		NS		NS	
Shimmer (Hz)	3.03 ± 0.9	2.96 ± 1.7	3.03 ± 0.9	2.83 ± 1.12	2.96 ± 1.7	2.83 ± 1.1
P Value	> 0.05		> 0.05		> 0.05	
Sig.	NS		NS		NS	
H/N (Hz)	2.31 ± 3.4	−0.53 ± 3.3	2.31 ± 3.4	1.0 ± 2.9	−0.53 ± 3.3	1.0 ± 2.9
P Value	< 0.05		< 0.001		< 0.001	
Sig.	S		HS		HS	

Table 8 Comparison between the central frequency and the mean duration of the waveform in the three groups using *t*-test.

	Palatal group Mean ± SD	Tongue base group Mean ± SD	Palatal group Mean ± SD	Combined group Mean ± SD	Tongue base group Mean ± SD	Combined group Mean ± SD
Central freq. (Hz)	108 ± 24 Hz	332 ± 80 Hz	108 ± 24 hz	205 ± 68 Hz	332 ± 80 Hz	205 ± 68 Hz
P value	< 0.001		< 0.001		< 0.001	
t-test (Sig.)	HS		HS		HS	
Mean duration of snoring	0.45s	1.46s	0.45s	0.89s	1.46s	0.89s
P value	< 0.001		< 0.001		< 0.001	
t-test (Sig.)	HS		HS		HS	

Table 9 Average first formant (F1) values for the vowels /i/, /u/ and /a/ produced by the groups of OSA patients and non-OSA snorers.

Vowels	OSA	Non-OSA	*P* Value	*t*-test Sig.
/i/	299 ± 22	340 ± 37	< 0.05	S
/u/	335 ± 30	339 ± 31	> 0.05	Ns
/a/	522 ± 14	760 ± 68	> 0.05	Ns

Table 10 Average second formant (F2) values for the vowels /i/, /u/ and /a/ produced by the groups of OSA patients and non-OSA snorers.

Vowels	OSA	Non-OSA	*P* Value	*t*-test Sig.
/i/	1808 ± 83	2301 ± 140	< 0.05	S
/u/	767 ± 40	986 ± 91	< 0.001	Hs
/a/	971 ± 39	1230 ± 100	> 0.05	Ns

determine a positive oximetry trace and therefore the sensitivity and specificity of overnight pulse oximetry.

Several possible reasons can be put forward to explain these variations. When the population studied has a high prevalence of OSA the sensitivity and specificity of overnight pulse oximetry may improve because the accuracy of overnight pulse oximetry lies in the detection of apneas while hypopnoeas are undiagnosed [8,19]. Another explanation for the disparity of the results is the method of quantifying nocturnal desaturation [21]. Oximeters have different time responses and, depending on the settings, they can underestimate the number of desaturations. Modifying the average time of the pulse oximeter would account for up to 60% of underestimated desaturations [22].

Some of the criticism of the use of overnight oximetry as a diagnostic test rests on the concern that patients may not be sleeping. However, patients without cardiopulmonary disorders do not tend to desaturate. Moreover, it has been reported that neurophysiological parameters may play a less significant part than respiratory events [23]. Another disadvantage of overnight oximetry is that it is not possible to differentiate between desaturations occurring secondary to obstructive apneas, central apneas, primary pulmonary disease, and cardiac disease using overnight oximetry. Thus, its role in the investigation of OSA is contentious as it is less sensitive and specific than PSG [5,18,19]. There is, however, another drawback with overnight pulse oximetry. In OSA, the clinically important event is arousal, whereas the pulse oximeter measures

Table 11 Average first bandwidth (BW1) values for the vowels /i/, /u/ and /a/ produced by OSA patients and non-OSA snorers.

Vowels	OSA	Non-OSA	*P* Value	*t*-test Sig.
/i/	70 ± 21	57 ± 21	< 0.05	S
/u/	65 ± 31	53 ± 19	< 0.05	S
/a/	135 ± 85	136 ± 34	> 0.05	Ns

Table 12 Average second bandwidth (BW2) values for the vowels /i/, /u/ and /a/ produced by OSA patients and non-OSA snorers.

Vowels	OSA	Non-OSA	*P* Value	*t*-test Sig.
/i/	89 ± 30	66 ± 33	< 0.05	S
/u/	191 ± 86	130 ± 66	< 0.05	S
/a/	213 ± 90	101 ± 40	< 0.001	Hs

desaturations and changes in heart rate which are secondary phenomena [17].

The sensitivity and specificity of screening oximetry are dependent on the severity of OSA: the lower the value of the apnea–hypopnea index the higher the specificity of oximetry but the poorer the sensitivity, whereas higher values lead to higher sensitivity but reduced specificity. Our results suggest that oximetry alone allows confident recognition of moderate and severe cases of OSA but it is inadequate for exclusion of milder cases. Equivocal results is likely and repeat oximetry or more detailed polysomnography will then be required if clinical suspicion is high. The false negative group was misclassified by oximetry because of a failure to demonstrate significant falls in saturation ($\geqslant$4% from baseline SaO_2). This may in large part be explained by their less severe disease, as evidenced by fewer and shorter apneas than in those patients correctly identified as positive for sleep apnea [3].

Phoniatric assessment

CT scanning provides excellent imaging of the airway, soft tissue, and bony structures from the nasopharynx to larynx. Images from CT scanning are only obtained in the axial plane, but three-dimensional CT construction of the upper airway, tongue, and soft palate may provide information concerning the area most likely obstructed [24]. Sleep studies in a sleep laboratory help to exclude patients with sleep apnea and quantify the intensity and duration of snoring; however, they cannot determine the exact site of snoring [25].

Acoustic analysis of snoring sounds would offer the advantage of a non-invasive technique that would be used to monitor normal sleep. Experienced clinicians often remark that it is easy to differentiate the low frequency rattle of palatal snoring from the more high pitched strangulated sound of tongue base obstruction.

In order to try and to demonstrate this scientifically this work has concentrated on the waveform and frequency analysis of the snoring sounds aiming at differentiation of different kinds of snoring sounds according to their site of obstruction. The characteristics of the snoring sound vary from case to case and depend on the source of the sound [26].

The purpose of this study was to find a way of predicting the site of airway obstruction by analyzing the snoring sound acoustically.

In this study, the use of flexible nasopharyngoscopy was tolerated by all patients. All the patients included in this study were examined by the endoscope and the degree of collapse at the cross sectional area at the retro palatal and retro lingual areas was observed.

During the Muller's maneuver, varying degrees of collapse occur. It ranges from slight narrowing to complete collapse of the pharyngeal airway. In patients with tongue base obstruction, we observed large bulky tongue base.

Acoustic analysis of voice

Formant frequencies

Formant frequencies reflect the sound resonating properties of the vocal tract during vowel production. Vowels yield three distinct vocal tract resonances, formant 1 (F1), formant 2 (F2), and formant 3 (F3).

In the present work, study of the formant frequencies and formants bandwidths (BW) of different vowels (i, u and a) in OSA patients and non-OSA snorers revealed that the mean

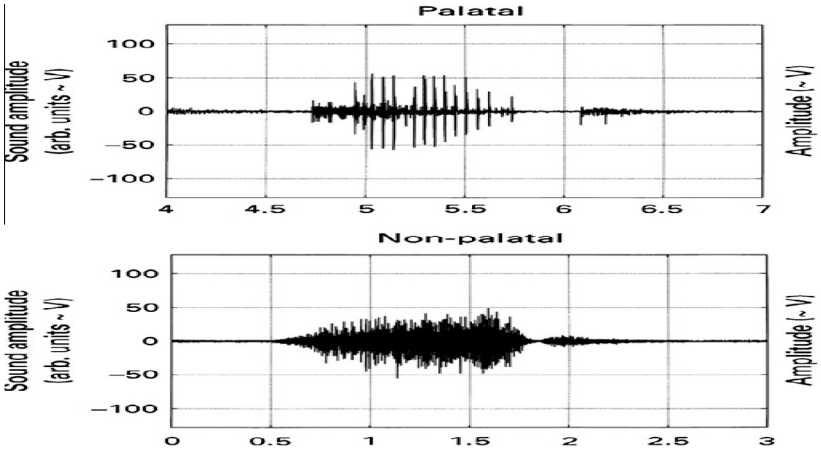

Figure 9 Waveform patterns of palatal and tongue base snoring.

F1 value for the vowel /i/ was significantly lowered in OSA patients compared with non-OSA snorers. In addition, the mean F2 value of the vowel /i/ and /u/ was markedly lowered in OSA patients compared with non-OSA snorers. This means that there were no significant changes between non-OSA snorers and normal individuals as regards F1.The same findings were observed for F2 in normal individuals and non-OSA snorers.

Hirano [27] studied the normal values of F1 for the vowels /i/, /u/ and /a/ among normal individuals. The results were 336 ± 31, 351 ± 42 and 755 ± 67 Hz respectively.

In addition, in the present study we found that, BW1 and BW2 values of the vowels /i/ and /u/ were wider in OSA patients than those obtained in non-OSA snorers.

The results obtained for BW1 and BW2 indicated obvious differences between OSA patients and non-OSA snorers. The formant bandwidths for the OSA patients were wider across each vowel type. The wide bandwidths among OSA patients support the hypothesis that these individuals may display greater than normal vocal tract compliance. The significant compliance tends to dampen sound traversing the vocal tract.

Hirano [27] studied the normal values of BW1 for the vowels /i/, /u/ and /a/ among normal individuals. The results were 55 ± 20, 60 ± 21 and120 ± 32, respectively. This means that there were no significant changes between non-OSA snorers and normal individuals as regards BW1and BW2.

Acoustic analysis of snoring sounds

(a) Waveform analysis

In the present, the waveform pattern of the snoring sound of the palatal group patients showed a series of impulses. These impulses had a similar pattern throughout snoring sounds of the same individual. Each impulse represents a single cycle of opening and closing of the nasopharyngeal airway. These impulses are characterized by distinguished repetitive cycles of opening and closure of the nasopharyngeal airway. The waveform showed mean frequency duration (0.45 s) and frequency range 52–288 Hz.

In addition, the waveform pattern of tongue base snoring was made up of higher frequency oscillations. These impulses were of a less repeatable morphology and occurred at a higher frequency than the impulses observed in the palatal snorers. The waveform had wider mean frequency duration (1.46 s) and wider frequency range (54–766) than those produced by palatal snoring (Fig. 9).

In addition, the waveform of the combined type snoring sounds showed features of both patterns, this is because the snoring sounds may be generated from tonsils, tongue or the lateral pharyngeal walls.

These features of different waveforms may be explained by that palatal snoring is characterized by rapid repetitive cycles of opening and closure of the nasopharyngeal airway. Tongue base snoring appears to be associated with airflow turbulence in a rapid, continuous air flow through a severely narrowed airway. Turbulence induced sound produced by tongue base has a higher frequency and broader frequency range than that produced by the floppy soft palate intermittently obstructing the nasopharyngeal airway. The tongue base is too stiff and bulky to vibrate against the posterior pharyngeal wall so; the waveform was different in shape from that produced by the soft palate. The difference in method of sound generation explains the lack of impulses in the waveform and the higher frequency spectrum of tongue base snoring.

However, in this study we could not identify a certain characteristic pattern for the waveform between patients of simple snoring and patients with OSA. This may be explained by the fact that the shape of the waveform is determined by the site at which the snoring sound is generated, and it is not determined by the degree of apnea.

Quinn et al. [28] studied ten adult patients who were known to suffer from heavy snoring but not OSA using sleep nasopharyngoscopy. The mechanism of snoring was noted for each patient and sound recording of the snoring noise was made. Six subjects were observed to snore using their soft palate only, three snored using only tongue base and one snored using a combination of palate and tongue base. The sound waveform pattern of palatal snoring was characterized by a series of impulses. These impulses were of similar pattern throughout a single snore but they were varied in shape from snorer to snorer. The waveform pattern of tongue base snoring was made up of higher frequency vibrations with irregular nature.

(b) Average pitch, Jitter, Shimmer and Harmonic to noise ratio (H/N)

In the present study, we found that there are significant differences between average pitch between the 3 groups. In the palatal group, the average pitch was 105 ± 8 Hz and in the tongue base group the average pitch was 263 ± 17 Hz and the average pitch in the combined group was 160 ± 14 Hz.

These results agree with the finding obtained by Miyazaki et al. [26] who reported that the average value of fundamental frequency was 102.8 ± 34 in the soft palate group, 331.7 ± 14 in the tongue base group and 115.7 ± 58 in the combined group.

Agrawal et al. [29] found palatal snorers had a median peak of 136 Hz and tongue base snorers had a peak at 1243 Hz.

These findings together with the findings obtained in this study stated that the palatal snoring had a low average pitch frequency and the tongue base snoring had a high average pitch frequency, so, the two sounds could be identified acoustically on the basis of the average pitch frequency.

As regards jitter and shimmer analysis of snoring sounds, we did not find significant differences between the 3 groups, however we found increased harmonic to noise ratio in patients with tongue base obstruction. This finding revealed that more noise is generated in patients with tongue base snoring than patients with palatal snoring.

(c) Central frequency

Frequency analysis of palatal snoring showed a mean centre frequency 108 ± 24 Hz. Tongue base snoring produces sound of higher frequency. The mean centre frequency for the tongue base snoring was 332 ± 80 Hz and the mean centre frequency of the combined type was 205 ± 68 Hz.

We concluded that there are distinct patterns of waveform could be demonstrated for both tongue base snoring and palatal snoring, and it is possible to differentiate between tongue base snoring and palatal snoring on the grounds of waveform pattern. Using the criteria of centre frequency greater or less than 200 Hz and frequency deviation greater or less than 60 Hz, the tongue base snoring and palatal snoring could be clearly differentiated from each other.

These results agree with the findings obtained by Quinn et al. [28] who reported that the difference between tongue base snoring and palatal snoring is audible and it is likely that a trained ear could differentiate between these two types of snoring.

Conclusion

- Polysomnography is the current golden standard test for diagnosis and evaluation of degree of OSA.
- Overnight pulse oximetry offers an inexpensive method of screening for and diagnosing OSA. The sensitivity and specificity of screening oximetry are dependent on the severity of OSA. Oximetry alone allowed confident recognition of moderate and severe cases of OSA but it is inadequate for exclusion of milder cases. Equivocal results are likely and repeat oximetry or more detailed polysomnography will then be required if clinical suspicion is high.
- Acoustic analysis of snoring sounds and voice in patients with snoring and/or OSA is useful as a screening or supportive method with other investigations to diagnose the site of upper airway obstruction during sleep, also it is useful as a screening method to differentiate between simple snoring and OSA patients.
- Acoustic analysis of snoring sounds could become a useful tool in clinical sleep medicine to separate individuals with apnea from those with simple snoring and to aid in differentiating palatal snoring from tongue base snoring.

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