ANTHROPOMETRIC AND ACOUSTIC PHARYNGOMETRIC PARAMETERS IN SLEEP-DISORDERED BREATHING DUE TO STRUCTURAL PHARYNGEAL ALTERATIONS

Galen Shivarov

Division of Otorhinolaryngology, St. Anna Hospital of Varna

ABSTRACT

INTRODUCTION: Sleep-disordered breathing is a medico-social problem of rising importance worldwide. There are various clinical forms of sleep apnea such as obstructive sleep apnea (OSA) and central sleep apnea as well as snoring. Recently, there have been considerable advances in the diagnosis of OSA and snoring.

AIM: This study aimed at applying the method of acoustic pharyngometry for the diagnosis of pharyngeal alterations in subjects with sleep-disordered breathing within a preventive otorhinolaryngological programme in the city of Varna for the first time in Bulgaria.

MATERIALS AND METHODS: Between January 1, 2016 and August 31, 2019, screening for sleep-disordered breathing was performed among 100 subjects, 62 males at a mean age of 48.82±11.45 years and 38 females at a mean age of 52.42±16.54 years in the Division of Otorhinolaryngology, St. Anna Hospital of Varna. Clinical inspections, anterior rhinoscopy, pharyngoscopy, indirect laryngoscopy, acoustic rhinometry, as well as acoustic pharyngometry by means of Eccovision® acoustic pharyngometer were used. The t-test for independent variables and the correlation analysis were applied for statistical data processing.

RESULTS: The acoustic pharyngometry identified several pharyngeal alterations. There were statistically significant changes of the anthropometric parameters (body mass index, neck circumference and adjusted neck circumference) and pharyngometric ones (pharyngeal cavity and vocal tract lengths and volumes) between males and females. There were statistically significant positive and negative correlations between the values of these parameters.

CONCLUSION: Within the complex otorhinolaryngological examination of the pharyngeal structure and function in the subjects suspected for sleep-disordered breathing, acoustic pharyngometry could play an irreplaceable role as a cost-effective tool.

Keywords: *acoustic pharyngometry, sleep-disordered breathing, pharyngeal cavity dimensions, vocal tract dimensions, correlations*

Address for correspondence:
Galen Shivarov, MD, PhD
Division of Otorhinolaryngology
St. Anna Hospital of Varna
100 Tsar Osvoboditel Blvd
9002 Varna
e-mail: docshivarovbg@abv.bg

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INTRODUCTION

Sleep-disordered breathing is a medico-social problem of rising importance worldwide. In other countries, acoustic pharyngometry is widely used among the rich armamentarium of diagnostic capacities such as polysomnography, the gold standard in this field, computed tomography, magnetic resonance imaging, ultrasound, polygraphy, ApneaGraph, home sleep apnea testing with portable devices, and acoustic rhinometry as well.

The prevalence of moderate to severe sleep-disordered breathing in the USA between 1988-1994 and 2007-2010 using data from the Wisconsin Sleep Cohort Study among 1520 participants aged between 30 and 70 years amounts to 10% among 30-49-year-old men, 17% among 50-70-year-old men, 3% among 30-49-year-old women, and 9% among 50-70 year-old women (1).

In *PubMed*, *EMBASE* (Ovid), *the Cochrane Library*, and *CINAHL,* 89 relevant clinical studies including 7096 patients report prevalence and/or severity of sleep-disordered breathing after stroke or transitory ischemic attack (2). Mean apnea-hypopnea index is 26.0 events/hour (between 21.7 and 31.2 events/hour). There is prevalence of the sleep-disordered breathing with apnea-hypopnea index >5 events/hour and >30 events/hour in 71% and 30% of the patients, respectively.

The prevalence of sleep-disordered breathing among population-based sleep cohorts in Japan is 24.0-83.8% in men and 9.0-76.6% in women while that of moderate-to-severe sleep-disordered breathing is 7.2-67.2% in men and 4.0-50.9% in women (3).

Between October 2010 and January 2015, in Alexandria, Egypt, among 129 females and 115 males at a mean age of 56.9 years with obstructive sleep apnea syndrome (OSAS) and with a mean apnea-hypopnea index of 43.6 events/hour, 93 patients (38.11%) present with mild and moderate OSAS, while the remaining 151 ones (61.89% of the cases) present with severe, very severe, and extreme OSAS (4). There are comorbidities in 222 patients (in 90.98% of the cases).

Between 2004 and 2008, the overall prevalence of habitual snoring in 512713 Chinese participants aged 30 to 79 years is 21.2% (5). It is higher among men, in southern regions, and urban areas as well. This prevalence increases among current and past smokers and alcohol consumers as well. The risk of habitual snoring increases by 19% per 1 kg/m^2 increment of body mass index and by 6% per 1 cm increment of waist circumference.

In a cross-sectional study of 866 participants between 2007 and 2016 in China, simple snorers present with more severe metabolic disorders and higher prevalence of metabolic syndrome than non-snorers (6). There is a significant linear trend between snoring intensity and metabolic score. After multivariable adjustment, simple snoring is significantly associated with increased odds ratios for metabolic syndrome, arterial hypertension, abdominal obesity, and hypertriglyceridemia among all participant and among females as well as for arterial hypertension among males.

AIM

The objective of this study was to summarize the preliminary results from the otorhinolaryngological screening by using conventional and modern tools for early diagnosis of sleep-disordered breathing among adults in the city of Varna.

MATERIALS AND METHODS

Between January 1, 2016 and August 31, 2019, screening for sleep-disordered breathing was performed among 100 subjects in the Division of Otorhinolaryngology, St. Anna Hospital of Varna within a Sleep Apnea Prevention Programme of the Municipality of Varna. There were 62 males at a mean age of 48.82±11.45 years (range, 20 to 74 years) and 38 females at a mean age of 52.42±16.54 years (range, 21 to 85 years). They complained of common daily somnolence and snoring. Participants' distribution according to gender and 20-year age groups is demonstrated on Fig. 1.

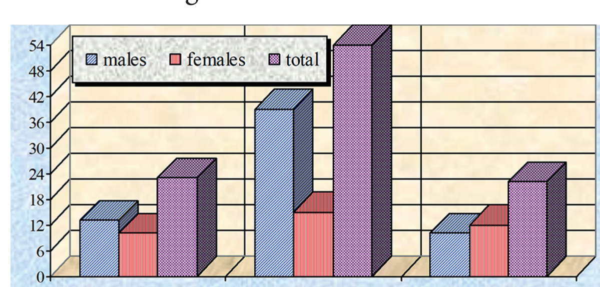

Fig. 1. Participants' distribution according to gender and age

A constellation of the following diagnostic methods was used: clinical inspections, anterior rhinoscopy, pharyngoscopy, indirect laryngoscopy, acoustic rhinometry, and acoustic pharyngometry in sitting position. Four specific parameters, such as pharyngeal cavity and vocal tract lengths and volumes, were assessed using the Eccovision® acoustic pharyngometer (HOOD Laboratories, Boston, MA, USA) for the first time in Bulgaria. The anthropological measurements included neck circumference, height and weight. Individual body mass index and adjusted neck circumference were calculated. Additionally, all the participants filled in an Epworth Sleepiness Scale questionnaire and reported their concerns related to sleep-disordered breathing.

The *t*-test for independent variables and the correlation analysis by Pearson and Spearman coefficients were applied for statistical data processing.

RESULTS

We proved the variety of rhinopharyngological diagnoses and pathological findings in patients' sleep-disordered breathing detected by means of the constellation of the clinical and specific acoustic pharyngometric and rhinometric examinations.

The two most common pathological findings or diagnoses, i.e. low soft palate (LSP) and uvula elongation, were established. They could be objectively assessed by means of pharyngoscopy and acoustic pharyngometry only. It should be noted that most participants presented with several simultaneous pathological findings or diagnoses as demonstrated on Fig. 2.

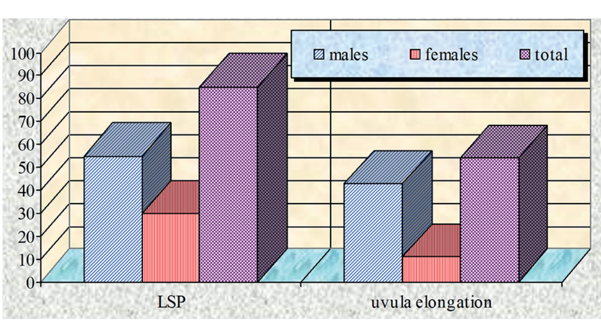

Fig. 2. Participants' distribution according to the number of pathological findings or diagnoses in the same subject

The distribution of LSP and uvula elongation according to gender is demonstrated on Fig. 3 but their relative shares among the whole sample were shown in Table 1.

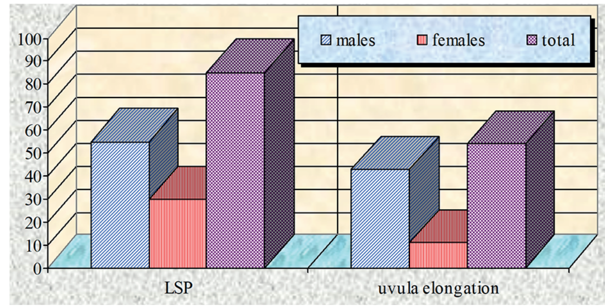

Fig. 3. Distribution of two common pathological findings or diagnoses according to participant's sex

Table 1. Relative share of two pathological findings (in %)

Pathological findings or diagnoses	Males (n=62)	Females (n=38)	Total (n=100)
LSP	88.71	79.95	85.00
Uvula elongation	69.35	28.95	54.00

The values of the anthropometric parameters of all the participants from *t*-test for independent variables are demonstrated in Table 2.

Table 2. Values of the anthropometric parameters in all participants

Parameter	Minimal	Maximal	Mean	SD
Neck circumference	29.00	62.00	40.05	5.43
Adjusted neck circumference	31.50	65.00	45.59	6.57
Body mass index	19.10	46.20	29.47	5.78

The values of four pharyngometric parameters in males and females from *t*-test for independent variables are shown in Table 3.

The results from *t*-test for independent variables concerning four pharyngometric parameters in males and females are presented in Table 4.

There were statistically significant differences concerning the vocal tract length (t=-2.457; p=0.016) and vocal tract volume (t=-2.467; p=0.017).

Table 3. Values of four pharyngometric parameters in males and females

Parameter	Minimal	Maximal	Mean	SD	SE
Males (n=62)					
Pharyngeal cavity length	5.60	12.90	8.17	1.69	0.21
Pharyngeal cavity volume	3.57	30.53	9.85	6.77	0.86
Vocal tract length	12.60	21.35	16.26	1.96	0.25
Vocal tract volume	16.03	74.43	37.67	12.51	1.59
Females (n=38)					
Pharyngeal cavity length	4.00	12.00	8.44	1.73	0.28
Pharyngeal cavity volume	3.03	26.09	12.09	6.45	1.04
Vocal tract length	12.80	21.36	17.21	1.77	0.29
Vocal tract volume	16.79	101.03	46.59	20.04	3.25

Table 4. Values of independent variables concerning four pharyngometric parameters in males and females

Levene's test for equality of variables							
Pharyngeal cavity length							
F	Significance	*T*	p	Mean difference	Mean error of the difference	95% confidence interval for mean	
						Lower bound	Upper bound
0.029	0.864	-0.763	0.447	-0.269	0.352	-0.967	0.430
Pharyngeal cavity volume							
F	Significance	*T*	p	Mean difference	Mean error of the difference	95% confidence interval for mean	
						Lower bound	Upper bound
0.007	0.933	-1.636	0.105	-2.241	1.370	-4.959	0.478
Vocal tract length							
F	Significance	*T*	p	Mean difference	Mean error of the difference	95% confidence interval for mean	
						Lower bound	Upper bound
1.164	0.283	-2.457	0.016	-0.955	0.389	-1.727	-0.184
Vocal tract volume							
F	Significance	*T*	p	Mean difference	Mean error of the difference	95% confidence interval for mean	
						Lower bound	Upper bound
7.113	0.009	-2.467	0.017	-8.926	3.619	-16.179	-1.673

The values of the anthropometric and pharyngometric parameters of the participants aged below and over 40 years are compared in Table 5.

The results from the *t*-test for independent variables concerning four pharyngometric parameters between the participants from these two age groups are shown in Table 6.

There was a statistically significant difference concerning the pharyngeal cavity length only (t=-2.374; p=0.020).

Table 5. Values of three anthropometric and four pharyngometric parameters of the participants aged below and over 40 years

Parameter	<40 years (n=23)			≥40 years (n=77)		
	Mean	SD	SE	Mean	SD	SE
Anthropometric parameters						
Neck circumference	38.587	4.940	1.030	40.493	5.518	0.629
Adjusted neck circumference	42.674	6.326	1.319	46.461	6.425	0.732
Body mass index	26.652	5.317	1.109	30.310	5.678	0.547
Pharyngometric parameters						
Pharyngeal cavity length	7.552	1.592	0.332	8.493	1.688	0.192
Pharyngeal cavity volume	10.317	7.044	1.469	10.811	6.,644	0.757
Vocal tract length	16.282	2.099	0.438	16.725	1.885	0.215
Vocal tract volume	42.921	17.696	3.690	40.503	15.935	1.816

Table 6. Values of independent variables concerning four pharyngometric parameters in the participants from the two age groups

Levene's test for equality of variables							
Pharyngeal cavity length							
F	Significance	*T*	p	Mean difference	Mean error of the difference	95% confidence interval for mean	
						Lower bound	Upper bound
0.528	0.469	-2.374	0.020	-0.940	0.396	-1.726	-0.154
Pharyngeal cavity volume							
F	Significance	*T*	p	Mean difference	Mean error of the difference	95% confidence interval for mean	
						Lower bound	Upper bound
0.008	0.930	-0.309	0.758	-0.494	1.601	-3.670	2.682
Vocal tract length							
F	Significance	*T*	p	Mean difference	Mean error of the difference	95% confidence interval for mean	
						Lower bound	Upper bound
0.264	0.609	-0.963	0.338	-0.443	0.460	-1.356	0.470
Vocal tract volume							
F	Significance	*T*	p	Mean difference	Mean error of the difference	95% confidence interval for mean	
						Lower bound	Upper bound
0.030	0.863	0.623	0.535	2.419	3.884	-5.290	10.130

The mean Epworth Sleepiness Scale scores of the participants from these two age groups are summarized in Table 7.

The results from the *t*-test for independent variables concerning the mean Epworth Sleepiness Scale scores between the participants from these two age groups are demonstrated in Table 8.

The analysis of the correlations between age or gender, Epworth Sleepiness Scale scores, and three anthropometric parameters, on the one hand, and four specific pharyngometric parameters, on

Table 7. Mean Epworth Sleepiness Scale scores of the participants aged below and over 40 years

Subjects	Mean	SD	SE
<40 years (n=23)	6.30	4.14	0.86
≥40 years (n=77)	8.60	5.16	0.59

Table 8. Values of independent variables concerning the mean Epworth Sleepiness Scale scores between the participants from the two age groups

Levene's test for equality of variables							
F	Significance	*T*	p	Mean difference	Mean error of the difference	95% confidence interval for mean	
						Lower bound	Upper bound
0.500	0.481	-1.950	0.054	-2.293	1.176	-4.626	0.040

the other hand, revealed several positive and negative values of the Pearson and Spearman correlation coefficients.

The Pearson correlations were the following: between patient's age, on the one hand, and Epworth Sleepiness Scale scores (r=0.254; p=0.011) and pharyngeal cavity length (r=0.227; p=0.023), on the other hand; between Epworth Sleepiness Scale scores, on the one hand, and adjusted neck circumference (r=0.197; p=0.049) and body mass index (r=0.255; p=0.011), on the other hand; between pharyngeal cavity length, on the one hand, and pharyngeal cavity volume (r=0.474; p=0.0001), vocal tract length (r=0.617; p=0.0001), and minimal distance (r=-0.210; p=0.036), on the other hand; between pharyngeal cavity volume, on the one hand, and vocal tract length (r=0.479; p=0.0001) and vocal tract volume (r=0.673; p=0.0001), on the other hand as well as between vocal tract length, on the one hand, and vocal tract volume (r=0.491; p=0.0001), on the other hand.

The Spearman correlations were the following: between patient's gender, on the one hand, and neck circumference (r=-0.771; p=0.0001), adjusted neck circumference (r=0.706; p=0.0001), body mass index (r=0.352; p=0.0001), pharyngeal cavity volume (r=0.213; p=0.034), vocal tract length (r=0.241; p=0.016) and vocal tract volume (r=0.227; p=0.023), on the other hand; between Epworth Sleepiness Scale scores, on the one hand, and adjusted neck circumference (r=0.262; p=0.009) and body mass index (r=0.240; p=0.016), on the other hand; between neck circumference, on the one hand, and adjusted neck circumference (r=0.885; p=0.0001), body mass index (r=0.638; p=0.0001) and vocal tract length (r=-0.206; p=0.040), on the other hand; between adjusted neck circumference, on the one hand, and body mass index (r=0.661; p=0.0001), vocal tract length (r=-0.274; p=0.006) and vocal tract volume (r=-0.200; p=0.046), on the other hand; between pharyngeal cavity length, on the one hand, and pharyngeal cavity volume (r=0.491; p=0.0001) and vocal tract length (r=0.595; p=0.0001), on the other hand; between pharyngeal cavity volume, on the one hand, and vocal tract length (r=0.473; p=0.0001) and vocal tract volume (r=0.648; p=0.0001), on the other hand as well as between vocal tract length, on the one hand, and vocal tract volume (r=0.488; p=0.0001), on the other hand.

DISCUSSION

We established some quantitative peculiarities of the pharyngeal dimensions detected by acoustic pharyngometry in our male and female subjects with breathing disorders during sleep.

There are single studies devoted to sleep apnea-related pharyngeal alterations detected by this new method.

In 50 severe obstructive sleep apnea and hypopnea syndrome (OSAHS) patients, the distance of minimal cross-sectional area from the nostril is 2.06±0.12 cm; the pharyngeal cross-sectional area is 0.87±0.12 cm^2 and the pharyngeal cross-sectional volume is 9.24±2.31 cm^3 (7). The pharyngeal cross-sectional area and volume are statistically significantly lower in patients than in control subjects (p<0.01).

In ten obese patients at a mean age of 55±9 years presenting with obstructive sleep apnea and hypopnea, with a mean body mass index of 35.1±6.1 kg/m^2, a mean apnea-hypopnea index of 58.8±27.1 events/hour and a mean Epworth Sleepiness Scale score of 12.3±3.6 points, the maximal pharyngeal area is 2.28±0.74 cm^2 initially, 2.79±0.90 cm^2 after one week, and 2.94±0.33 cm^2 after six months (one week and six months versus basal conditions; $p<0.05$) (8). The mean pharyngeal area is 1.43±0.46 cm^2 initially, 1.82±0.45 cm^2 after one week, and 1.94±0.35 cm^2 after six months (one week and six months versus basal conditions; $p<0.05$).

In 145 women at a mean age of 42.9±15.1 years, the pharyngeal area at the oropharyngeal junction is negatively related to body mass index, waist, hip and sagittal abdominal diameter while the mean pharyngeal area is negatively related to body mass index and to sagittal abdominal diameter in orthostatic position only (9).

Acoustic pharyngometry findings in 27 subjects, 13 males at a mean age of 22.2±4.47 years (range, 17-35 years) and with a mean body mass index of 26.70±5.47 kg/m^2 (range, 21.36 to 42.9 kg/m^2) and 14 females at a mean age of 21.7±2.99 years (range, 19-29 years) and with a mean body mass index of 23.63±2.98 kg/m^2 (range, 19.1 to 30.1 kg/m^2) reveal that length and volume of the oral, pharyngeal, and vocal tract cavities are statistically significantly smaller in the supine than in the upright position ($p<0.0001$ for all) (10).

Recently, some modern imaging methods have increasingly been used for the precise diagnosis of the structural pharyngeal alterations which induce sleep-related breathing disorders.

A quantitative magnetic resonance imaging is used to classify the retropalatal airway patterns in 20 simple snorers and 97 obstructive sleep apnea (OSA) patients (11). Both the cross-sectional area at the hard palate level and the retropalatal lateral dimension are associated with OSA. Such patients have longer pharynges than control subjects. The oblique pattern is associated with narrow lateral dimensions while the vertical one is related to a narrow nasopharynx but a longer pharynx. The anatomical imbalances between the craniofacial skeletal and soft tissue structures affect pharyngeal airway morphology in all three dimensions. The dimensions of the nasopharynx, the cross-sectional area at the hard palate level, and pharyngeal length are associated with the retropalatal patterns and OSA severity.

Six examiners perform airway analysis, including manual orientation, slice and threshold selection and measure nasopharyngeal, oropharyngeal, hypopharyngeal and total upper pharyngeal airway volumes as well as minimum cross-sectional area on the cone beam computed tomography images of ten patients (12). The minimum cross-sectional area shows moderate intra- and poor inter-examiner reliability. Intra-examiner reliability of volumetric measurements is worst for hypopharynx and best for oropharynx while inter-examiner reliability is worst for nasopharynx and best for oropharynx.

A simultaneous measurement of respiratory flow and airway calibre using ultrafast dynamic computed tomography is performed in 23 OSA patients and eight normal subjects (13). The pharyngeal cross-sectional area changes are compared across different OSA severities. Airway distensibility during the expiratory phase of awake respiration correlates with OSA severity. The slope of this relationship is significantly higher in severe OSA than in mild to moderate OSA and normal controls.

The volumetric and anatomical changes in the posterior airway space are measured by computed tomography and cone beam computed tomography in 55 OSAS patients (14). The posterior airway space height and cross-sectional area are statistically significantly higher in cone beam computed tomography than in computed tomography scans ($p<0.001$). The three-dimensional evaluation shows a statistically significantly greater posterior airway space volume in cone beam computed tomography ($p<0.0001$).

In patients with acromegaly and OSAHS, computed tomography detects a statistically significantly thicker soft palate ($p=0.024$), larger soft palate cross-sectional area ($p=0.027$) and thicker lateral pharyngeal wall ($p=0.015$) than in patients with acromegaly but without OSAHS (15). The maximal transverse diameter ($p=0.015$) and cross-sectional area ($p=0.032$) of the airway decrease in the soft palate plane in patients with OSAHS. The apnea-hypopnea index correlates positively with the thickness of the soft palate and lateral pharyngeal wall but does so negatively with the maximal transverse diameter and cross-sectional area of the airway in the soft palate plane.

CONCLUSION

Within the complex otorhinolaryngological examination of the pharyngeal structure and function in adults and children suspected for sleep-disordered breathing, acoustic pharyngometry could play an irreplaceable role as a cost-effective tool. Screening programmes of this kind should be more widely used for preventive purposes in our country.

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