

Original article

## Functional condition of inspiratory muscles in obstructive sleep apnea patients

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**Abstract: Background** — Recurrent upper airway obstruction during the sleep is a key feature of obstructive sleep apnea (OSA). In patients with OSA, an intermittent upper airway obstruction yields an increase in inspiratory effort and, consequently, an augmented impact on inspiratory muscles (IM). However, the issue of IM fatigue development in OSA patients is still controversial.

**Objective** — to investigate the functional condition of IM in patients with OSA of various degrees of severity.

**Material and Methods** — Were examined 82 men (30-65 years old), who were distributed among four groups depending on the OSA severity. Cardiorespiratory monitoring was performed to detect OSA. IM electrical activity was detected via surface electromyography (EMG) while holding the breath (during the inhalation).

**Results** — In the course of our study, we detected a reduction in the frequency of EMG of accessory IM, specifically sternocleidomastoid muscle (SCMM) and external intercostal muscles (EIM), accompanied by a simultaneous increase in the amplitude of EMG of SCMM, EIM, and diaphragm (D), while holding the breath (during the inhalation), in the group of patients without OSA. In patients with mild OSA, when holding the breath during the inhalation, the frequency of EMG of SCMM and EIM decreased, while the amplitude of SCMM and EIM increased. In patients with moderate OSA, when holding the breath during the inhalation, a decrease in the frequency of SCMM EMG with a simultaneous increase in the amplitude of the EIM EMG were revealed. Same maneuver in the group of patients with severe OSA yielded no significant changes in the frequency and amplitude of EMG of respiratory muscles.

**Conclusion** — Periodic obstruction of the upper airways with OSA leads to the development of fatigue resistance in accessory IM.

**Keywords:** obstructive sleep apnea, inspiratory muscles, electromyography.

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### Introduction

Recurrent upper airway obstruction during sleep is a key feature of obstructive sleep-related disorder called obstructive sleep apnea (OSA) [1]. In patients with OSA, intermittent obstruction of the upper airways yields an increase in inspiratory effort and, consequently, an augmented impact on inspiratory muscles, and also the development of hypoxemia [2]. Extreme stress on the diaphragm in patients with OSA could be a risk factor for developing inspiratory muscle (MI) fatigue [3]. Besides, hypoxemia contributes to the development of respiratory muscle (RM) fatigue during inspiratory stress. However, an issue of the IM fatigue development in OSA patients still remains controversial. Montserrat, et al. reported that there was no evidence about overnight diaphragm (D)

fatigue in patients with OSA [4]. They proposed that inspiratory effort, leading to the overnight fatigue, did not last long enough to develop the disorders of RM contractility. Vincken, et al. [5] did not find EMG indications of D fatigue in OSA patients as well, even though the values of the stress-time index of D were higher than the values of D fatigue threshold at the end of an apnea episode. On the contrary, evaluating a random sniff test at the end of night sleep in OSA patients, Griggs, et al. detected impaired IM contractility, as evidenced by a decrease in the maximum strength characteristic of transdiaphragmatic pressure [6]. To date, there are practically no data in the literature on the functional condition of accessory IM in patients with OSA. It is known that D plays a leading role in forming inspiratory effort, but the implementation of the normal biomechanism of inhalation requires the coordinated participation

of accessory IM. Without the latter, an effective change in the chest volume cannot take place [7]. It should be noted that when assessing blood circulation in the RM at loads of varying intensity, it was shown that the sternocleidomastoid muscle (SCMM) has the least adaptive reserve [8]. Therefore, the issue of the IM resistance, both main and accessory, to the development of fatigue in patients with OSA of varying severity is of a special interest.

Study objective: to investigate the functional condition of IM in patients with OSA of various degrees of severity.

## Material and Methods

### Study participants

The study was approved by the local Ethics Committee at Orenburg State Medical University of the Russian Federation Ministry of Healthcare.

Since our subjects were not previously examined for the presence of OSA, we conducted their cardiorespiratory monitoring via the ApneaLink system (ResMed, Germany), involving the study of their nasal airflow, pulse rate, and oxygen saturation. The diagnosis of OSA was established with an Apnea/Hypopnea Index (AHI) of  $\geq 5$  events per hour sensu 2014 International Classification of Sleep Disorders, version 3. Currently, an episode of sleep apnea/hypopnea is identified by a decrease in the nasal airflow by 50% or more, accompanied by either desaturation of over 3%, or EEG activation (microarousal), lasting 10 seconds or more. OSA severity is identified by the following scale of AHI values (in events per hour): mild OSA corresponds to AHI values of 5-15, moderate OSA is characterized by higher values (up to 30), and severe OSA occurs when AHI exceeds 30.

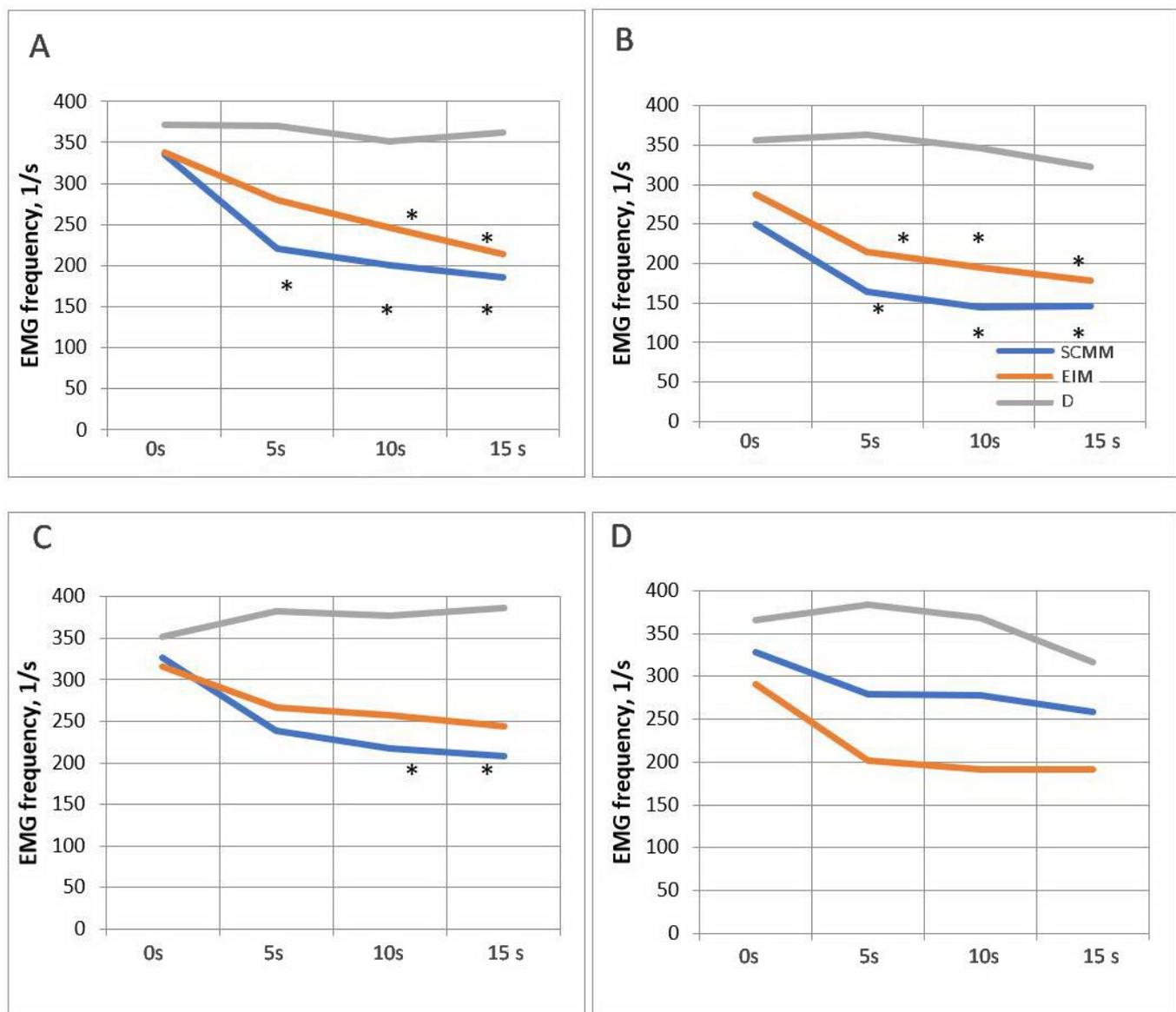
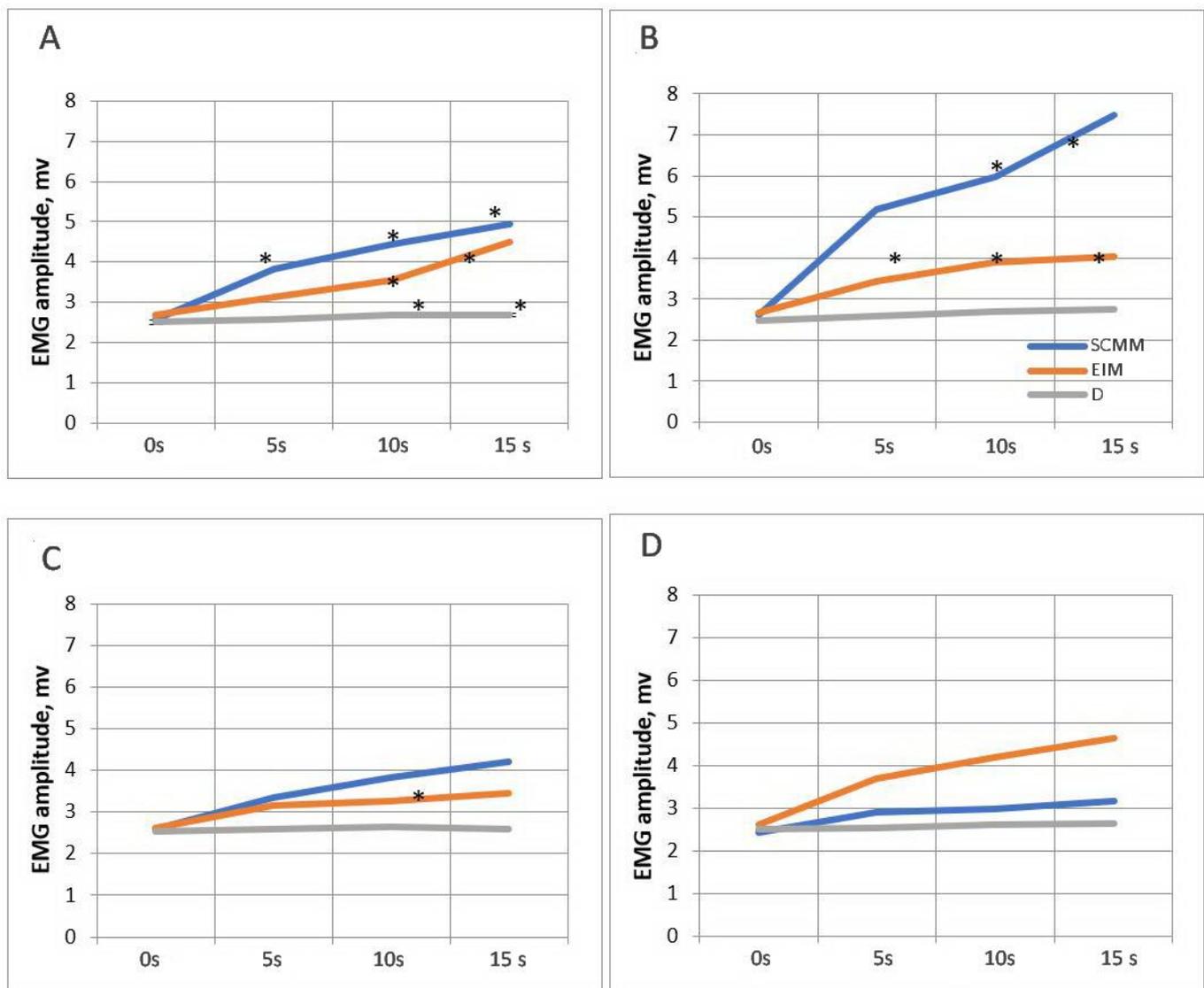


Figure 1. EMG frequency in surveyed groups.

A – group of patients without OSA; B – group of patients with mild OSA; C – group of patients with moderate OSA; D – group of patients with severe OSA. SCMM, sternocleidomastoid muscle; EIM, external intercostals muscles; D, diaphragm; \* statistically significant changes in the group, compared with the initial frequency ( $p < 0.05$ ).



**Figure 2. EMG amplitude in surveyed groups.**

A – group of patients without OSA; B – group of patients with mild OSA; C – group of patients with moderate OSA; D – group of patients with severe OSA. SCMM, sternocleidomastoid muscle; EIM, external intercostals muscles; D, diaphragm; \* statistically significant changes in the group, compared with the initial frequency ( $p \leq 0.05$ ).

According to the inclusion criteria, 82 men, who signed informed voluntary consent to participate in the study, 30-65 years of age, were examined. They were were distributed among four groups depending on the presence and severity of OSA, assessed from the data of cardiorespiratory monitoring. Group 1 included 24 SA-free patients, Group 2 encompassed 24 patients with mild OSA, Group 3 was represented by 17 subjects with moderate OSA, and Group 4 comprised 17 patients with severe OSA. The groups were randomized in terms of age.

The inclusion criteria were as follows: male gender, age range of 30-65 years old, OSA in anamnesis, and signed informed voluntary consent to participate in the study. The exclusion criteria were: refusal to participate in the study, aggravated heart rhythm disorders, heart failure, history of myocardial infarction, acute cerebrovascular accident, high-risk obesity (Class 3), diseases of respiratory system, operations on the chest organs in anamnesis, diseases with impaired neuromuscular transmission, intake of

medications that slow down neuromuscular transmission, and presence of pronounced deformity or pathological shape of the chest.

#### **Surface electromyography of respiratory muscles**

Recording of the IM electrical activity was carried out using bipolar surface electromyography (EMG) on the Neuro-MEP multifunctional computer complex (Neurosoft, Russia) with a frequency bandwidth from 2 Hz to 10 kHz. The assessment of the IM electrical activity, including D, external intercostals muscles (EIM) and SCMM, was carried out using the indicators of the average amplitude ( $\mu V$ ) and frequency (1/s). The surface electrodes were metal disks 8 mm in diameter mounted in a fixing block with an interelectrode distance of 12 mm. At the place where the electrodes were applied, the skin was pretreated with an alcohol-containing skin antiseptic, and then the electrode gel was applied. During EMG, to avoid interference from the heart,

the electrodes were placed on the right side of the body. To register the electrical activity of D, electrodes were placed in the 7th intercostal space at the level of the outer edge of the rectus abdominis muscle; for electrical activity of EIM, they were placed along the midclavicular line in the 3rd intercostal space; and for SCMM, the electrodes were attached on the bottom of the muscle 2-3 cm above the clavicle [9]. The values of indicators were recorded at rest and during the execution of an inspiratory maneuver (holding the breath while inhaling). The subject was in a comfortable position, sitting on a straight back chair. Prior to the test, the value of the maximum inspiratory effort was determined individually for each patient on the scale of the original pressure indicator protected by the rationalization proposal. Measurements were stopped after reaching the differences among three consecutive values of under 10%. Of those three values, the maximum value of the individual inspiratory effort was selected, on the basis of which the power was calculated equal to 30% of the maximum inspiratory effort individually for each subject.

Then the maneuver was carried out with holding the breath at 30% of the maximum inspiratory effort for 15 seconds and with recordings of EMG indicators at 5, 10, and 15 seconds. This technique allowed us assessing the formation of RM fatigue. Each maneuver was performed three times, with a rest period of 3 minutes between the attempts. For the analysis, we used the average values of EMG indicators obtained as a result of three attempts when performing an inspiratory maneuver.

The voluntary exercise of forming the maximum inspiratory effort requires the elimination of subjectivity in its implementation, which was achieved by selecting the patients motivated to participate in the study, and by detailed instructions on the technique of holding the breath while inhaling, during which a special emphasis was placed on the necessity to apply the maximum effort. In the course of executing the maneuver, a visual control of the level of maintained inspiratory effort by the subject and the researcher was carried out, accompanied by verbal stimulation for its implementation. Visual control of the maintained inspiratory effort level was conducted via using a pressure indicator, which reflected the current level of inspiratory effort, expressed in kilopascals. When deviating from the established range limits, the subject was advised to amplify or reduce the inspiratory effort, so that its values were back to the established limits. If a subject was unable to maintain the inspiratory effort within the established limits, the maneuver was terminated.

Data were not included in the study if differences in values of over 10% were recorded during the successive execution of three inspiratory sessions.

For processing biological EMG signals, we used the Neuro-MEP software (Neurosoft, Russia), followed by the analysis of the average amplitude (mV) and the average frequency (1/s), based on the data of turn-amplitude analysis.

#### Statistical data processing

We employed STATISTICA 10 software package (Statsoft, Russia) to process the data obtained as a result of our study. The normality of data distribution was assessed using Shapiro-Wilk test; the distribution was considered normal at  $p \geq 0.05$ . Since distributions of all studied indicators were different from normal, nonparametric methods were used for their analysis. We presented our data as Me (Q1; Q3). One-way analysis of variance

(ANOVA) via Fisher's F-test was used to assess intragroup differences in parameter values. The data were considered statistically significant at  $p < 0.05$ .

#### Results

Holding breath while inhaling in the OSA-free group of patients yielded reduction in the EMG frequency of accessory IM (Figure 1A), specifically of SCMM and EIM, which was confirmed by the analysis of variance ( $F_{SCMM}=31.930$ ,  $p=0.000$ ;  $F_{EIM}=3.7231$ ,  $p=0.016$ ). There were no significant changes in the EMG frequency of D while maintaining the inspiratory effort. During the inspiratory maneuver, simultaneously with EMG frequency reduction, we observed an increase in EMG amplitude of SCMM, D and EIM (Figure 2A) ( $F_{SCMM}=5.2937$ ,  $p=0.003$ ;  $F_{EIM}=6.237$ ,  $p=0.001$ ;  $F_D=2.801$ ,  $p=0.048$ ).

When assessing the amplitude-frequency EMG characteristics of IM in patients with mild OSA, the following changes were revealed: the EMG frequencies of SCMM and EIM (Figure 1B) significantly decreased when inspiratory effort was maintained ( $F_{SCMM}=20.3923$ ,  $p=0.000$ ;  $F_{EIM}=8.348$ ,  $p=0.000$ ); there were no significant changes in the EMG frequency of D; at the same time, the amplitudes of SCMM and EIM increased ( $F_{SCMM}=4.83726$ ,  $p=0.005$ ;  $F_{EIM}=3.6802$ ,  $p=0.016$ ), and more pronounced amplitude increase of SCMM was observed than in OSA-free patients; EMG amplitude of D did not change significantly (Figure 2B). In patients with mild OSA, when performing the exercise with holding the breath on inhalation, no significant changes in the parameters of the EMG amplitude of D were detected.

As shown in Figure 1C, in patients with moderate OSA, when performing the inspiratory effort maneuver, no significant changes in the EMG frequency of EIM and D were revealed; however, the EMG frequency of SCMM significantly decreased ( $F_{SCMM}=3.1852$ ,  $p=0.039$ ). At the same time, the study of indicators of IM amplitude (Figure 2B) in patients with moderate OSA, yielded no significant changes in EMG amplitude of SCMM and D, whereas EMG amplitude of EIM was increasing when holding the breath on inhalation ( $F_{EIM}=3.814$ ,  $p=0.021$ ).

When assessing the amplitude-frequency characteristics (Figures 1D and 2D) during the inspiratory effort maneuver in the group of patients with severe OSA, no significant changes in the frequency and amplitude of EMG were detected.

#### Discussion

In the course of our study, we discovered that when performing an exercise with holding breath, while inhaling, in OSA-free patients, we observed an increase in the EMG amplitude of both D (the main respiratory muscle), and SCMM and EIM (accessory IM). As was demonstrated in previously conducted studies, an increase in the EMG amplitude correlates with an increase in the strength of the muscle contraction, which is formed when additional motoneurons are recruited [10].

It should be noted that when performing a functional test, the subjects were asked of keeping their inspiratory effort at a constant level. Therefore, it could be assumed that an increase in the EMG amplitude compensated for the developing fatigue process, as evidenced by a reduction in the EMG frequency. With prolonged voluntary contraction, EMG indicators gradually change their characteristics due to disorders in the excitability of muscle fibers. Such EMG changes are manifested by reduced EMG

frequency values, or else by a shift of the centroid frequency towards lower frequencies [11, 12]. At the same time, in patients without OSA, we observed a decrease in the EMG frequency of SCMM and EIM, but not of D; hence it can be concluded that an increase in the EMG amplitude of D in the absence of a frequency decrease compensates for fatigue of the accessory IM.

In the group of patients with mild OSA, we detected an increase in the EMG amplitude with a simultaneous reduction in the frequencies of accessory IM, which were more pronounced than in patients without OSA. At the same time, there were no significant changes in the EMG amplitude and frequency of D. Thus, in patients with mild OSA, fatigue of accessory IM occurs when the inspiratory effort is maintained, which is compensated by an increase in the strength of muscle contraction via the mechanism of involvement of additional motor neurons.

In patients with moderate OSA, a reduction in the EMG frequency of SCMM was revealed as a sign of fatigue, compensated by an increase in the amplitude of EIM, but there was no pronounced fatigue of EIM, which indicated a change in the mechanism of forming the inspiratory effort in conditions of a static load. In patients with severe OSA, we detected neither the formation of IM fatigue, nor an increase in the EMG amplitude.

All described findings imply that as OSA progresses, a greater resistance of the accessory IM to fatigue, formed in the course of a static inspiratory load, develops. It is well known that training via holding the breath, while inhaling – i.e., by means of a static inspiratory effort, similar to the impact on IM, which occurs with OSA – leads to an increase in IM resistance to fatigue [13-15]. The adaptive effect of recurrent hypoxia on muscles is a well-known fact [16].

It was established that a decrease in the number of functioning capillaries in the muscle contributed to the deterioration of its functional condition. In this regard, it can be assumed that the presence of comorbid pathology in patients with OSA, for example, of diabetes mellitus, complicated by microangiopathy with impaired blood circulation in skeletal muscles and related RM, may lead to maladjustment of IM. The latter, in turn, may lead to the fatigue or weakness of RM. Accordingly, further study of the IM functional condition with simultaneous presence of OSA and diabetes mellitus is of substantial interest.

### Conclusion

We can conclude that periodic obstruction of the upper airways, forming with OSA, has a training effect on accessory IM, which compensates for aggravated dysfunctions of the pharyngeal muscles with an increase in the OSA degree.

### Limitations

Since the prevalence of OSA in men is higher than in women, only men were included in our study. The type of breathing differs depending on gender and is characterized by different biomechanics of inhalation. Hence, our data obtained should not be extrapolated to the female population, and the functional condition of IM in women with OSA requires an additional study.

**Conflict of interest:** none declared.

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