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ORIGINAL ARTICLE

Pulmonology

Spectral Analysis of Cough Sounds in Patients with Chronic Bronchitis

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Abstract

Background: Cough is the main symptom of chronic bronchitis (CB). However, the literature does not provide information on the characteristics of the cough sound in CB patients. The objective of this study was to conduct a spectral analysis of the cough sound in CB patients compared with the cough in patients with bronchial asthma (BA), chronic obstructive pulmonary disease (COPD), and coronavirus disease 2019 (COVID-19) and an induced cough in healthy individuals.
Methods and Results: The study's main group consisted of 60 patients with CB in the stage of exacerbation (46.6% men and 53.4% women; mean age of 47.6 (46; 49) years). The comparison groups consisted of patients with BA (n=21), COPD (n=20), COVID-19 (n=20) and healthy individuals (n=20). The cough sounds were recorded using the spectral tussophonobarography method based on the Fast Fourier Transform Algorithm, allowing the distribution of sound energy by frequency. We estimated the time-frequency parameters of sounds of the entire cough episode, as well as for separated phases of the cough sound: duration (T, T1, T2, T3), the ratio of the energy of low and medium frequencies (60–600 Hz) to the energy of high frequencies (600–6000 Hz) (Q, Q1, Q2, Q3), and the frequency of maximum sound energy (Hz) (Fmax, $Fmax_1$, $Fmax_2$, $Fmax_3$).
The cough parameters in the main group and the comparison groups had significant differences. Thus, the total duration of cough in CB patients was more prolonged than in COVID-19 patients. T1 and T3 were more extended in CB patients than in all comparison groups, and T2 was shorter than in patients with BA, COPD, and healthy individuals.
In the second cough phase, low-frequency energy was predominant in patients with CB, compared to BA. In contrast, the lowest frequencies were predominant in COPD patients, compared to CB patients. Fmax and $Fmax_1$ in CB were significantly lower than in BA patients. $Fmax_2$ in CB patients was lower than in BA patients but higher than in healthy individuals with induced coughs. $Fmax_3$ was significantly lower in CB than in all comparison groups. The cough of patients with CB has reliable differences in the main frequency-time characteristics compared to the cough sound of patients with BA, COPD, and COVID-19. This may indicate that spectral tussophonobarography can help in the differential diagnosis of chronic bronchitis.(**International Journal of Biomedicine. 2025;15(2):285-290.**)

Keywords: cough • spectral sound analysis • chronic bronchitis

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Abbreviations

BA, bronchial asthma; **CB**, chronic bronchitis; **COPD**, chronic obstructive pulmonary disease; **COVID-19**, coronavirus disease 2019

Introduction

According to official statistics, cough is one of the most common reasons for seeking medical help.[1,2] The prevalence of chronic cough in Russia is up to 14.8%.[3]

It is known that the causes of cough are variable. These include diseases of the bronchopulmonary, cardiovascular, and nervous systems, as well as pathology of the nasopharynx, gastrointestinal tract, taking certain medications, etc.[4] Among the above, respiratory diseases occupy a leading position. In first place in this group of cough causes is chronic bronchitis (CB). The prevalence of chronic bronchitis in the Russian Federation is 10–20%.[3]

One of the reasons for the high prevalence of cough is the lack of objective methods for its diagnosis available for clinical use today. All currently existing methods for diagnosing this symptom are subjective. In particular, subjective methods include a visual analogue scale, a point assessment of cough severity, and questionnaires such as LCQ, CQLQ, CSS, and CSD. These methods play a role in making a diagnosis; however, they cannot evaluate cough objectively, with a comprehensive assessment of its parameters as a sound phenomenon.

At the moment, special devices to examine cough objectively have been developed abroad. These are the semi-automatic cough recording systems called VitaloJAK and CayeCoM (The Cayetano Cough Monitor) and the automated devices LCM (Leicester Cough Monitor) and HACC (The Hull Automatic Cough Counter).[5] Mobile application developments can be used to study cough, for example, those proposed by Hoyos-Barceló et al. [6] and Claxton et al.[7]

In 1993, in Russia, at the Department of Faculty Therapy of the Voronezh State Medical University named after N.N. Burdenko, Professor Vyacheslav Provotorov and engineers from the Voronezh Experimental Design Bureau of Machine Building developed the ICT-1 tussograph.[8] Later, at the Department of Faculty Therapy, spectral analysis of cough sounds was conducted in patients with various pathologies. Using the spectral tussophonobarography method, the cough sound was studied in diseases such as bronchial asthma (BA), chronic obstructive pulmonary disease (COPD), and gastroesophageal reflux disease (GERD).[9,10] Studies of cough parameters in patients with coronavirus disease 2019 (COVID-19) have been completed.[11,12]

The objective of this study was to conduct a spectral analysis of the cough sound in CB patients compared with the cough in patients with BA, COPD, and COVID-19 and an induced cough in healthy individuals.

Materials and Methods

The research was conducted from April 2023 to September 2024. The study's main group included 60 patients suffering from non-obstructive catarrhal or mucopurulent chronic bronchitis of mild severity in the acute stage (46.6% men, 53.4% women; mean age of 47.6 (46; 49) years). The comparison groups included patients with uncontrolled moderate persistent BA in the moderate exacerbation stage (n=21: 47.6% men and 52.4% women; mean age of 50.2 (44.8; 50.7) years), COPD GOLD II, category B, moderate exacerbation (n=20: 55% men and 45% women; mean age of 53.3 (44.9; 56.3) years), healthy individuals (n=20: 50% men and 50% women; mean age of 48.8 (38.9; 58.7) years), patients with COVID-19 of moderate severity with lung damage less than 25% according to chest X-ray computed tomography, without previous chronic respiratory diseases (n=20: 45% men and 55% women; mean age of 51.8 (40.6; 53.3) years).

The diagnosis of chronic bronchitis was made in accordance with current clinical guidelines based on complaints, anamnesis, objective examination of the patient, laboratory and instrumental data, and questionnaires.[3]

The main interest of the research was the sound of cough. All patients had their cough sounds recorded using a microphone. The subjects were instructed on how far away the microphone was (15–20 cm from the face) and how hard they should cough so that the sound would be approximately the same in amplitude. An involuntary cough was recorded. In healthy individuals, cough was induced by inhaling a citric acid solution (maximum concentration 20 g/L).[13]

The frequency-time characteristics of cough were assessed using the spectral tussophonobarography method, which is based on the Fast Fourier Transform Algorithm, allowing the distribution of sound energy by frequency.[13]

To normalize the volume of the resulting cough recording (up to 6 dB), set the sampling frequency (up to 48000 Hz), and divide the coughing act into phases, the SoundForge 16 program (MAGIX Software GmbH, Germany) was used.

From a biomechanical point of view, the cough sound can be divided into phases (Figure 1): Phase 1 is the opening of the glottis; Phase 2 is a rapid air release from the lungs; Phase 3 is the closing of the glottis. Phase 3 may be absent in about a third of patients.

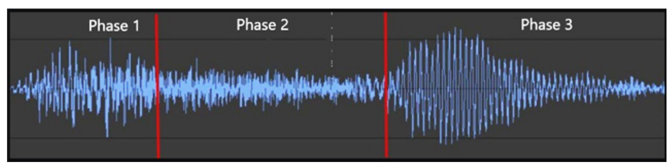

Fig. 1. *Division of a coughing episode into phases*

For analyzing cough sound using spectral tussophonobarography, the following parameters are required:

T – duration time (ms)

Q – the ratio of the total energy of low and medium frequencies (60–600 Hz) to the energy of high frequencies (600–6000 Hz)

Fmax – frequency of maximum sound energy (Hz)

These parameters were assessed both for the entire cough recording and by phases.

Mathematical and statistical data processing was assessed using the Statistica 10 software package (StatSoft, Tulsa, Oklahoma, USA). The sample's compliance with the Gaussian distribution was assessed using the Shapiro-Wilk criterion, as well as the coefficient of kurtosis and asymmetry. The obtained values were outside the interval from –2 to +2; therefore, the data distribution did not correspond to the normal one. Numerical indicators of cough parameters are presented as a median, with the upper and lower quartiles indicated in brackets. For comparative analysis, the Kruskal-Wallis test was used. Differences were considered statistically significant at a level of $P<0.05$.

Results

The main and comparison groups did not differ in gender and age. The results of the spectral analysis of cough in patients with CB, BA, COPD, and COVID-19, as well as healthy individuals, are presented in Table 1.

Table 1.
Spectral characteristics of the cough sound in patients with CB, BA, COPD, COVID-19, and healthy individuals.

Parameter	Chronic bronchitis (n=60)	Bronchial asthma (n=21)	COPD (n=20)	Healthy individuals (n=20)	COVID-19 (n=20)
T (ms)	485.5 (410.5; 550.0)	476.0 (424.0; 594.0)	477.0 (367.0;583.0)	393.5 (349.5;434.0)#	343.0 (271.5; 387.5)##
T1 (ms)	75.0 (60.5; 92.0)	47.0 (38.0; 68.0)*	45.0 (34.0; 49.0)**	47.0 (41.5; 51.5)#	49.5 (39.5; 65.0)##
T2 (ms)	234.0 (188.5; 296.5)	350.0 (237.0; 375.0)*	312.0 (239.0; 428.0)**	275.0 (205.5; 314.0)#	213.5 (183.0; 245.0)
T3(ms)	141.0 (106.0; 201.5)	94.0 (48.0; 176.0)*	69.5 (53.0; 88.5)**	101.0 (81.0; 128.0)#	78.5 (63.0; 111.0)##
Q	0.353 (0.226; 0.479)	0.284 (0.169; 0.315)*	0.413 (0.335; 0.573)	0.452 (0.383; 0.661)#	0.2625 (0.2275; 0.504)
Q1	0.46 (0.242; 0.75)	0.513 (0.38; 0.632)	0.709 (0.491; 0.813)	0.474 (0.313; 0.799)	0.2685 (0.2015; 0.5065)##
Q2	0.243 (0.191; 0.323)	0.1625 (0.121; 0.256)	0.348 (0.295; 0.523)**	0.328 (0.265; 0.468)	0.2445 (0.165; 0.3295)
Q3	1.097 (0.694; 101.0)	0.5425 (0.408; 1.102)*	0.7635 (0.544; 1.1395)	1.038 (0.841; 1.581)	0.721 (0.369; 1.1975)##
Fmax(Hz)	382.0 (292.0; 594.5)	1373.0 (505.0;1,771.0)*	363.0 (256.0; 381.0)	413.5 (260.0; 527.0)	448.5 (284.5; 533.0)
$Fmax_1$ (Hz)	363.0 (275.0; 607.0)	444.0 (384.0; 523.0)*	344.0 (280.0; 242.0)	415.5 (292.0; 547.0)	559.0 (296.0; 794.0)
$Fmax_2$ (Hz)	558.5 (380.5; 858.0)	1532.0 (1,224.0;1,873.0)*	369.0 (190.0; 527.0)	453.5 (468.0;1,307.0)	512.5 (294.5; 1,074.0)##
$Fmax_3$ (Hz)	232.2 (101.0; 372.5)	413.5 (323.0; 1,326.0)*	330.0 (257.5; 383.5)**	311.0 (205.5; 420.0)#	312.0 (214.5; 397.0)##

T, T1, T2, and T3 — duration (ms) of the cough act as a whole, Phase 1, Phase 2, Phase 3, respectively; Q, Q1, Q2, and Q3 — the ratio of the total energy of low and medium frequencies to the energy of high frequencies of the cough act as a whole, Phase 1, Phase 2, Phase 3, respectively; Fmax, Fmax1, Fmax2, Fmax3 — the frequency of maximum sound energy (Hz) of the cough act as a whole, Phase 1, Phase 2, Phase 3, respectively.
** — differences between the main group and the group of patients with BA are significant at p<0.05; ** — differences between the main group and the group of patients with COPD are significant at p<0.05; # — differences between the main group and the group of healthy individuals are significant at p<0.05; ##— differences between the main group and the group of patients with COVID-19 are significant at p<0.05.*

Comparative analysis of cough in CB patients with the comparison group revealed significant differences in the duration of the first phase of cough (*P*=0.003), the second (*P*=0.0022), and the third (*P*=0.0241) phases of cough. The first and third phases of cough in chronic bronchitis were longer, while the second, on the contrary, was shorter.

When comparing the ratio of the total energy of low and medium frequencies to the energy of high frequencies, a significant difference was found in the indicator Q total (*P*=0.001), Q2 (*P*=0.0066), and Q3 (*P*=0.0049). The cough episode as a whole in chronic cough, as well as the second and third phases, is characterized by the predominance of lower frequencies in comparison with the cough of patients with bronchial asthma.

Analysis of the frequency of maximum sound energy showed significant differences between study groups in the overall Fmax and $Fmax_1$, $Fmax_2$, and $Fmax_3$ (*P*=0.0001, *P*=0.03, *P*=0.0000, and *P*=0.0001, respectively). In the cough sound of patients with chronic bronchitis, the maximum frequency of sound energy was lower than in patients with bronchial asthma.

Comparison of CB patients with COPD patients showed significant differences in T1 (*P*=0.0001), T2 (*P*=0.0049), and T3 (*P*=0.0002). In CB patients, T2 was shorter than in COPD patients, and T1 and T3 were longer. Significant differences were also found between the groups in Q2 (*P*=0.006). The cough of CB patients, compared to the cough of COPD patients, was characterized by higher frequencies. Analysis of Fmax revealed significant differences in the third phase of cough (*P*=0.0001). In CB patients, $Fmax_3$ was lower than in COPD patients.

Comparative analysis of cough duration in patients with CB and induced cough in healthy individuals revealed significant differences in T (*P*=0.016), T1 (*P*=0.001), T2 (*P*=0.0001), and T3 (*P*=0.0003). A significant difference in Q (*P*=0.014) and Q3 (*P*=0.01) was also revealed. The cough of patients with chronic bronchitis was characterized by higher frequencies than the cough of healthy individuals. Analysis of Fmax revealed significant differences in the third cough phase (*P*=0.0016). In CB patients, $Fmax_3$ was lower than in healthy individuals.

Comparative analysis of cough in patients with chronic bronchitis and patients of comparison groups revealed significant differences in the cough duration. The total duration of cough in CB patients was more prolonged than in COVID-19 patients. T1 and T3 were more extended in CB patients than in all comparison groups, and T2 was shorter than in patients with BA and COPD and healthy individuals.

Frequency response analysis showed significant differences in the first cough phase (*P*=0.0409) and the third (*P*=0.05). The frequency of cough sounds in BA patients was lower than in COVID-19 patients. Analysis of the Fmax indicator revealed significant differences in the third (*P*=0.0005) cough phase. $Fmax_3$ was significantly lower in CB than in all comparison groups. The cough of patients with CB has reliable differences in the main frequency-time characteristics compared to the cough sound of patients with BA, COPD, and COVID-19. The results of the comparative analysis of the frequency-time parameters of the second phase of cough sounds are presented in Figures 2-4.

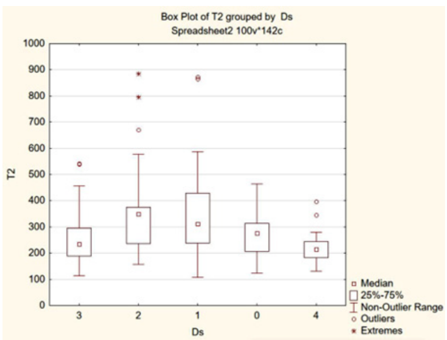

Fig. 1. *Division of a coughing episode into phases.*

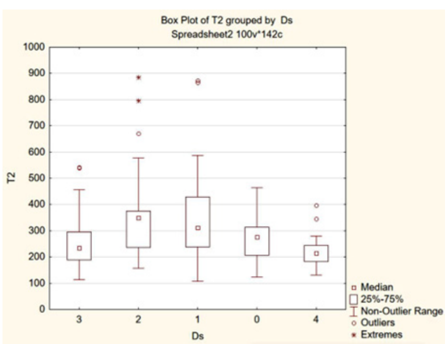

Fig. 2. *Time indicators of the second cough phase. The Y-axis shows the time data of T2; the X-axis shows the diagnoses: 4 - COVID-19; 3 - COPD; 2 - BA; 1 - CB; 0 — healthy individuals.*

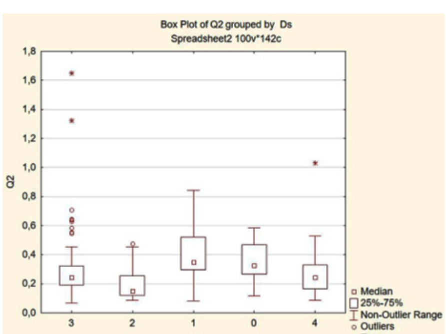

Fig. 3. *Frequency indicators of the second cough phase. The Y-axis shows the frequency characteristics of the second cough phase (T2); the X-axis shows the diagnoses: 4 – COVID-19; 3 – COPD; 2 – BA; 1 – CB; 0 – healthy individuals.*

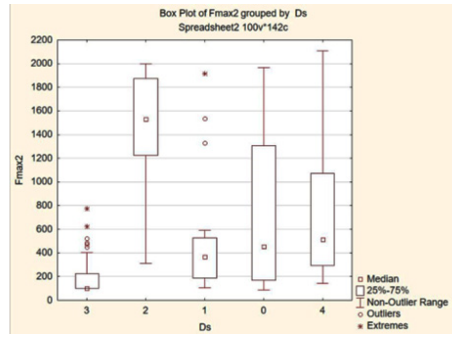

Fig. 4. *Maximum frequency of sound energy of the second cough phase. The Y-axis shows the maximum frequency of the sound energy of the second cough phase (T2; the X-axis shows the diagnoses: 4 – COVID-19; 3 – COPD; 2 – BA; 1 – CB; 0 – healthy individuals.*

Discussion

Having analyzed the above, we can conclude that there are reliable differences in the frequency-time parameters of the cough sound of patients with chronic bronchitis and cough of patients with bronchial asthma, COPD, and COVID-19 and the induced cough of healthy individuals. The duration of cough in CB in the whole cough episode and by phases is longer than in the comparison groups. The frequency of cough sound in CB is generally lower than in patients with BA, but higher than the cough of patients with COPD. The maximum frequency of sound energy is generally lower than in all comparison groups. The exception is the comparison of BA and cough of healthy individuals: in the second phase, the maximum frequency of cough sound energy in CB was higher.

The second cough phase is particularly interesting; it is also called compression. It is responsible for air passage through the respiratory tract. In the second phase, possible differences in the parameters of the cough sound are expected, which can be explained by pathogenetic mechanisms.

In the third cough phase, the glottis is rapidly closed after the contraction of the adductor muscles of the arytenoid cartilages, followed by adduction of the vocal cords. At the same time, a strong contraction of the abdominal muscles and other expiratory muscles occurs, which leads to an increase in intrapulmonary pressure and compression of the alveoli and bronchioles. The third phase is called “voice” or “ringing”. Harmonic analysis revealed some features of different phases of cough sounds.[14]

Attempts to objectify cough were made in the last century. Various methods were used, such as assessing cough receptors’ sensitivity after inhaling a trigger causing cough and counting cough shocks.[15] As has been reviewed by Hall et al.,[16] attempts to objectively measure cough frequency have been made since the 1950s. In 1955, spectral analysis of respiratory sounds was first performed based on the fast Fourier transform.[17] One of the first computer systems for spectral analysis of cough sounds was developed in 1990 by Toop et al.[18]

For the first time, Professor Vyacheslav Provotorov and colleagues carried out tussophonobarography in the

Department of the Voronezh State Medical University named after N.N. Burdenko. Coughs of healthy individuals and patients suffering from bronchial asthma were analyzed. Of greater interest was the second phase. It turned out to be the longest in patients with bronchial asthma. In healthy patients, the duration of cough did not exceed 450 ms. In addition, the specificity and high repeatability of sound parameters were recorded in healthy individuals. Significant differences were observed in the frequency of maximum energy of cough sound in healthy subjects and BA patients with a moderate course of the disease.[19]

In another study, a comparative analysis of cough in patients with COPD and bronchial asthma was performed using spectral tussophonobarography.[19] The differences were found in the second phase, manifested by the predominance of mid-frequency energy in patients with COPD, compared to the cough of patients with bronchial asthma. Cough is also being studied abroad using spectral analysis, and, as was already stated above, various devices have even been created to analyze cough. In a recent study, Wang et al.[20] assessed the possibility of using neural networks for continuous cough analysis over 24 hours.

Spectral analysis of cough sounds in patients with chronic bronchitis has not been conducted in Russia or abroad. Thus, this study is the first to obtain the values of the spectral characteristics of the cough sound of patients with chronic bronchitis and conduct a comparative analysis with the sounds of cough in other pathologies.

Conclusion

The cough of patients with CB has reliable differences in the main frequency-time characteristics compared to the cough sound of patients with BA, COPD, and COVID-19. This may indicate that spectral tussophonobarography can help in the differential diagnosis of chronic bronchitis.

Ethical Considerations

The study was approved by the Ethics Committee of Voronezh State Medical University named after N.N. Burdenko (Protocol #8 dated 15.11.2023). Written informed consent was obtained from all included patients.

Competing Interests

The authors declare that they have no competing interests.

Disclaimer

The views expressed in the submitted article belong to the authors, not the university and funder.

References

1. Guide for General Practitioners (Family Doctors). Cough. 2015 Association of General Practitioners (Family Doctors) of the Russian Federation. (In Russian) Available from https://mirvracha.ru/article/kr_dlya_vop_kashel
2. Zaitsev AA. Cough: problems and solutions. Practical pulmonology.2020;2:78-86(In Russian). Available from https://chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.atmosphere-ph.ru/modules/Magazines/articles//pulmo/pp_2_2020_78.pdf
3. Clinical Recommendations "Chronic Bronchitis" (approved by the Ministry of Health of the Russian Federation, 2021). (In Russian). Available from https://spulmo.ru/upload/kr/OB_2022.pdf
4. Kum E, Guyatt GH, Devji T, Wang Y, Bakaa L, Lan L, Liu E, Mastrolonardo A, Couban R, O'Byrne PM, Satia I. Cough symptom severity in patients with refractory or unexplained chronic cough: a systematic survey and conceptual framework. Eur Respir Rev. 2021 Jul 13;30(161):210104. doi: 10.1183/16000617.0104-2021. PMID: 34261745; PMCID: PMC9518000.
5. Ovsyannikov ES, Avdeev SN, Budnevskiy AV, Drobysheva ES. [Cough Diagnosis: Present and Future]. Tuberculosis and Lung Diseases. 2021; 99(11):56-64. (In Russian). doi: 10.21292/2075-1230-2021-99-11-56-64
6. Hoyos-Barceló C, Monge-Álvarez J, Pervez Z, San-José-Revuelta LM, Casaseca-de-la-Higuera P. Efficient computation of image moments for robust cough detection using smartphones. Comput Biol Med. 2018 Sep 1;100:176-185. doi: 10.1016/j.compbiomed.2018.07.003. Epub 2018 Jul 17. PMID: 30016745.
7. Claxton S, Porter P, Brisbane J, Bear N, Wood J, Peltonen V, Della P, Smith C, Abeyratne U. Identifying acute exacerbations of chronic obstructive pulmonary disease using patient-reported symptoms and cough feature analysis. NPJ Digit Med. 2021 Jul 2;4(1):107. doi: 10.1038/s41746-021-00472-x. PMID: 34215828; PMCID: PMC8253790.
8. Averyanov AV, Pashkova TL. [Tussography is a method of cough monitoring]. Pulmonologiya. 1998;(2):28-30. (In Russian).
9. Semenkova GG, Provotorov VM, Ovsyannikov ES. [Study of cough caused by gastroesophageal reflux disease using tussography and spectral tussophobarography methods]. Pulmonology. 2006;(6):56-61. (In Russian)
10. Morice AH, Kitt MM, Ford AP, Tershakovec AM, Wu WC, Brindle K, Thompson R, Thackray-Nocera S, Wright C. The effect of gefapixant, a P2X3 antagonist, on cough reflex sensitivity: a randomised placebo-controlled study. Eur Respir J. 2019 Jul 4;54(1):1900439. doi: 10.1183/13993003.00439-2019. PMID: 31023843.
11. Budnevsky AV, Avdeev SN, Ovsyannikov ES, Feigelman SN, Choporov ON, Maksimov AV, Pertsev AV. [Spectral analysis of cough sounds in patients with COVID-19]. Pulmonology. 2022;32(6):834-841. (In Russian) doi:10.18093/0869-0189-2022-32-6-834-841
12. Budnevsky AV, Ovsyannikov ES, Avdeev SN, et al. [The role of spectral analysis of cough sounds in the diagnosis of COVID-19]. Therapeutic archive. 2024; 96(3):228-232 (In Russian) doi: 10.26442/00403660.2024.03.202636
13. Kelsall A, Decalmer S, Webster D, Brown N, McGuinness K, Woodcock A, Smith J. How to quantify coughing: correlations with quality of life in chronic cough. Eur Respir J. 2008 Jul;32(1):175-9. doi: 10.1183/09031936.00101307. Epub 2008 Feb 20. PMID: 18287128.

14. Chang AB, Irwin RS, O'Farrell HE, Dicpinigaitis PV, Goel S, Kantar A, Marchant JM. Cough Hypersensitivity Syndrome: Why Its Use Is Inappropriate in Children. J Clin Med. 2023 Jul 25;12(15):4879. doi: 10.3390/jcm12154879. PMID: 37568280; PMCID: PMC10419757.
15. Zhang M, Sykes DL, Brindle K, Sadofsky LR, Morice AH. Chronic cough-the limitation and advances in assessment techniques. J Thorac Dis. 2022 Dec;14(12):5097-5119. doi: 10.21037/jtd-22-874. PMID: 36647459; PMCID: PMC9840016.
16. Hall JI, Lozano M, Estrada-Petrocelli L, et al. The present and future of cough counting tools. J Thorac Dis 2020;12:5207-23. 10.21037/jtd-2020-icc-003
17. Turner RD, Birring SS. Measuring cough: what really matters? J Thorac Dis. 2023 Apr 28;15(4):2288-2299. doi: 10.21037/jtd-23-230. PMID: 37197542; PMCID: PMC10183488.
18. Toop LJ, Thorpe CW, Fright R. Cough sound analysis: a new tool for the diagnosis of asthma? Fam Pract. 1989 Jun;6(2):83-5. doi: 10.1093/fampra/6.2.83. PMID: 2663580.
19. Ovsyannikov ES, Avdeev SN, Budnevsky AV, Shkatova YS. Influence of Anxiety/Depression on the Subjective Evaluation of Cough in Patients with Chronic Obstructive Pulmonary Disease and Obesity. Medicina (Kaunas). 2019 May 14;55(5):134. doi: 10.3390/medicina55050134. PMID: 31091811; PMCID: PMC6572558.
20. Wang Y, Wahab M, Hong T, Molinari K, Gauvreau GM, Cusack RP, Gao Z, Satia I, Fang Q. Automated Cough Analysis with Convolutional Recurrent Neural Network. Bioengineering (Basel). 2024 Nov 1;11(11):1105. doi: 10.3390/bioengineering11111105. PMID: 39593765; PMCID: PMC11591875.

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