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The Role of Spectral Analysis of Cough Sounds in the Diagnostics of Pneumonia

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Abstract

Background: Community-acquired pneumonia (CAP) is a global healthcare problem and one of the leading causes of death and hospitalization among respiratory diseases. Cough is the most common symptom of pneumonia. Diagnosing pneumonia using cough sounds is a useful non-invasive test that can be performed outside a hospital. The objective of this study was to conduct a spectral analysis of cough sounds in patients with pneumonia compared with the cough in patients with asthma (BA), chronic obstructive pulmonary disease (COPD), coronavirus disease 2019 (COVID-19), and an induced cough in healthy individuals, using citric acid.

Methods and Results: The study's main group consisted of 65 patients with pneumonia (81.4% men and 18.6% women; mean age of 43.5 [18.0; 70.0] years). The comparison groups consisted of patients with BA (n=38), COPD (n=35), COVID-19 (n=40), and healthy individuals (n=45). The cough sounds were recorded using the spectral tussophonobarography method based on the Fast Fourier Transform Algorithm, which provides a frequency-based distribution of sound energy. 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, Fmax1, Fmax2, Fmax3).

The cough parameters in the main group and the comparison groups had significant differences. In patients with pneumonia, the total cough duration (T) and T2 were significantly shorter than in all comparison groups. In contrast, T1 was significantly prolonged compared with patients with COPD, BA, COVID-19, and healthy subjects with induced cough. T3 was significantly shorter in pneumonia than in healthy individuals with experimentally induced cough. Overall, cough episodes in pneumonia were characterized by a predominance of low-frequency energy compared with BA and COVID-19. During the first cough phase, the Q coefficient was significantly higher in pneumonia than in COVID-19. In the second cough phase, energy distribution shifted toward lower frequencies compared with asthma and toward higher frequencies compared with COPD and COVID-19. In the third cough phase, pneumonia-related cough demonstrated a significantly greater proportion of high-frequency energy than induced cough in healthy subjects. The maximum frequency (Fmax) in pneumonia was significantly lower than in COVID-19 and BA. Fmax1 was significantly lower than in all comparison groups. Fmax2 was significantly lower than in BA, COPD, and COVID-19. Fmax3 was also significantly lower in pneumonia compared with COVID-19.

Conclusion: Cough in patients with pneumonia demonstrates significant differences in key frequency–time characteristics compared with cough sounds in patients with BA, COPD, and COVID-19. These findings suggest that spectral tussophonobarography may be a useful tool for differential diagnosis of pneumonia. (**International Journal of Biomedicine. 2026;16(2):212-216.**)

Keywords: pneumonia • cough • spectral analysis

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Abbreviations

BA, bronchial asthma; **CAP**, community-acquired pneumonia; **COPD**, chronic obstructive pulmonary disease; **COVID-19**, coronavirus disease 2019; **STFBG**, spectral tussophonobarography.

Introduction

Community-acquired pneumonia (CAP) is an infectious lung inflammation contracted outside the hospital. CAP incidence among all adults can reach 14 cases per 1,000. Up to 50% of cases require inpatient hospitalization, and the mortality rate reaches 0.7 per 1,000 persons per year. The World Health Organization has reported that CAP accounts for 4 million deaths per year, representing 7% of total annual mortality.[1] Verification of pneumonia is based on the presence of radiologically confirmed focal pulmonary infiltration and clinical symptoms, identification of the causative pathogen, assessment of disease severity and prognosis, and detection of complications.[2] Pneumonia is a seasonal disease, with its peak incidence occurring during the autumn–winter period. The timely use of radiological diagnostic methods may be limited by heavy medical personnel workload, high demand for X-ray equipment in primary health care facilities, and limited access to appropriate diagnostic options in remote areas.

Clinically, the disease manifests with fever (77.1%), dyspnea (62.7%), chest pain/discomfort (52.5%), and increased sweating (20–50%).[3-6] One of the most common symptoms of pneumonia is a productive cough with sputum expectoration (78.1%).[4,7] Cough is among the most frequent complaints of patients seeking primary health care for respiratory diseases such as bronchial asthma (BA), chronic obstructive pulmonary disease (COPD), chronic bronchitis (CB), COVID-19, pertussis, and pneumonia.[8-11] Subjective methods of cough assessment do not allow verification of the diagnosis of pneumonia; rather, they serve as indirect measures reflecting the patient's perception of actual cough episodes rather than an objective evaluation of cough itself. Objective assessment aims to provide a quantitative and unbiased evaluation of cough as a physiological and pathological phenomenon. Various physical characteristics can be measured, including cough strength/intensity, frequency, and acoustic properties. Given that cough is a common symptom of pneumonia, its acoustic characteristics may have diagnostic value and could be considered an additional tool for early identification of disease probability.[12,13]

The objective of this study was to conduct a spectral analysis of cough sounds in patients with pneumonia compared with the cough in patients with asthma (BA), chronic obstructive pulmonary disease (COPD), coronavirus disease 2019 (COVID-19), and an induced cough in healthy individuals, using citric acid.

Materials and Methods

The study's main group consisted of 65 patients with non-severe pneumonia (81.4% men and 18.6% women; mean age of 43.5 [18.0; 70.0] years) without prior chronic respiratory diseases who were treated on an outpatient basis at Voronezh City Clinical Polyclinic №7 or hospitalized in the Pulmonology department of Voronezh City Clinical Emergency Hospital №1 from October 2024 to October 2025. The diagnosis of pneumonia was established in accordance with current clinical guidelines,[3] based on chest radiography or computed tomography (CT) findings. The first comparison group included 45 healthy individuals (78% male, 22% female; mean age of 45.3 [32.2; 53.0] years) without prior chronic respiratory diseases, in whom cough was induced by inhalation of citric acid.[9] The second comparison group consisted of 40 patients (73.68% male, 26.32% female; mean age of 43.1 [30.2; 51.0] years) diagnosed with confirmed COVID-19 (mild to moderate form). The third comparison group included 38 patients with moderate persistent BA in the phase of moderate exacerbation (82.74% male, 17.26% female; mean age of 38.3 [32.2; 48.1] years). The fourth comparison group comprised 35 patients with COPD, clinical group E, in the phase of moderate exacerbation (72.54% male, 27.46% female; mean age of 52.3 [41.2; 65.3] years). No significant differences in age or sex distribution were observed between the groups.

Spectral tussophonobarography (STFBG) was performed to assess cough sound characteristics in the study participants, allowing evaluation of cough duration and frequency distributions according to the methodology previously described.[14]

Cough sounds were recorded in all patients using a microphone. The recordings were normalized for amplitude (up to 6 dB), the sampling rate was set to 48,000 Hz, and each cough event was segmented into phases using Sound Forge 18 (MAGIX Software GmbH, Germany).

Each cough event was divided into three phases:

Phase 1 – opening of the glottis
Phase 2 – rapid air release from the lungs
Phase 3 – closing of the glottis.

Phase 3 may be absent in approximately one-third of patients.

Subsequently, spectral analysis of cough sounds was performed using the Fast Fourier Transform algorithm.

The following time–frequency parameters were evaluated:

- Total cough duration (T) and the duration of each phase separately (T1, T2, T3), ms
- The ratio of low-frequency energy and mid-frequency energy (60–600 Hz) to high-frequency energy (600–6000 Hz) for the entire cough event (Q) and for each phase separately (Q1, Q2, Q3)
- The frequency of maximum sound energy of the entire cough event (Fmax) and of each individual phase (Fmax1, Fmax2, Fmax3), Hz.

Statistical data processing was assessed using IBM SPSS Statistics 23 (SPSS: An IBM Company, USA). The sample's compliance with the Gaussian distribution was assessed using the Kolmogorov–Smirnov criterion. 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 $P<0.05$.

Results

Table 1 presents the indicators of the comparative analysis of the studied cough sound parameters.

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

Parameter	Pneumonia (n=65)	Healthy individuals (n=45)	COVID-19 (n=40)	Bronchial asthma (n=38)	COPD (n=35)
T (ms)	330.0 (253.0;410.0)	390.5 (358.2;456.5)*	343.5 (280.0;400.2)	501.0 (419.2;624.5) #	452.2 (368.0;538.0) ##
T1 (ms)	81.0 (58.5;102.0)	46.5 (37.7;55.2)*	45.0 (35.0;57.0)**	46.5 (37,0;58,0)#	44,9 (36,0;51,0)##
T2 (ms)	160.0 (124.0;211.5)	271.5 (202.7;321.7)*	227.0 (189.7;275.2)**	369.5 (286.0;467.7)#	311.0 (251.0;428.0)##
T3 (ms)	93.0 (88.6;41.2)	100.0 (71.0;131.0)*	82.0 (61.0;114.7)	81.0 (68.2;107.2)	71.0 (56.0;93.0)
Q	0.390 (0.302;0.673)	0.437 (0.366;0.563)	0.306 (0.223;0.448)**	0.305 (0.174;0.385)#	0.443 (0.316;0.547)
Q1	0.540 (0.354;0.811)	0.505 (0.444;0.671)	0.405 (0.262;0.578)**	0.626 (0.509;0.732)	0.505 (0.386;0.709)
Q2	0.254 (0.1835;0.447)	0.284 (0.207;0.402)	0.197 (0.197;0.289)**	0.181 (0.131;0.268)#	0.346 (0.258;476)##
Q3	0.590 (0.300;1.007)	0.970 (0.736;1.398)*	0.719 (0.478;1.108)	0.568 (0.412;1.106)	0.713 (0.464;1.026)
Fmax (HZ)	370.0 (219.0;482.0)	382.5 (258.7;490.5)	452.0 (273.7;1034.4)**	1.202.5 (357.0;1678.2)#	371.0 (328.0;453.0)
Fmax1 (HZ)	274.0 (213.0;542.0)	397.5 (258.7;565.5)*	440.0 (282.5;620.5)**	386.5 (291.2;567.0)#	337.0 (276.0;574.0)##
Fmax2 (HZ)	539.0 (331.0;1235.5)	1126.5 (226.5;1532.)	960.0 (352.0;1609.7)**	1382.5 (975.5;1832.5)#	414.0 (211.0;556.0)##
Fmax3 (HZ)	388.0 (234.5;532.0)	326.0 (218.2;433.7)	313.0 (246.0;402.2)**	358.5 (329.6;477.0)	338.5 (297.2;401.5)

T, T1, T2, and T3 - duration (ms) of the cough act as a whole, Phase 1, Phase 2, Phase 3, respectively; Q, QI, 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 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; #- 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.*

A comparative analysis of cough sounds in patients with pneumonia and in healthy individuals with induced cough revealed statistically significant differences in cough act duration, which was shorter across all cough phases in the pneumonia group. When comparing the Q coefficient, significant differences were observed only in the third phase of cough (Q3). In pneumonia, low-frequency energy predominated. Analysis of the maximum sound energy frequency revealed significant differences in Fmax only in the first phase of cough (Fmax1), which was lower in patients with pneumonia.

Comparison between patients with pneumonia and COVID-19 showed statistically significant differences in T1 and T2 of the cough act. The duration of the first phase was shorter in the COVID-19 group, whereas the duration of the second phase was longer in the pneumonia group. When comparing the Q coefficients, significant differences were observed in the second and third cough phases (Q2 and Q3), with low-frequency energy predominating in pneumonia. Fmax showed significant differences throughout the entire cough act: Fmax, Fmax1, and Fmax2 were significantly lower in patients with pneumonia, while Fmax3 was higher.

Comparative analysis of cough sounds in patients with pneumonia and those with BA revealed significant differences in overall cough duration (T) and in the first (T1) and second (T2) phases. In pneumonia, overall T and T2 were significantly shorter, whereas T1 was significantly longer. Statistically significant differences in the Q coefficient were observed across the entire cough act and in the second phase, with low-frequency energy predominating in pneumonia. The maximum sound energy frequency (Fmax) in pneumonia was significantly lower for the entire cough act and in the first and second phases.

Comparative analysis of cough sounds in patients with pneumonia and those with COPD revealed significant differences in overall cough duration (T) and in the first (T1) and second (T2) phases. In pneumonia, overall T and T2 were shorter, whereas T1 was longer. When comparing the Q coefficient, statistically significant differences were detected only in the second phase of the cough act, with low-frequency energy predominating in COPD. Fmax showed significant differences in the first (Fmax1) and second (Fmax2) phases. Compared with COPD, the maximum sound energy frequency in pneumonia was significantly lower in the first phase and significantly higher in the second phase.

Discussion

The study results demonstrate that the time–frequency characteristics of cough sounds in pneumonia differ significantly from those in patients with COVID-19, COPD, BA, and citric acid–induced cough in healthy individuals, suggesting diagnostic and differential diagnostic value. Cough in patients with pneumonia is characterized by a shorter cough act duration and a predominance of low-frequency energy. The shift of the energy spectrum toward lower frequencies may be caused by inflammatory consolidation of lung tissue, decreased elasticity, and increased mass of the oscillating medium due to intra-alveolar exudation.

In COVID-19, the predominance of high-frequency energy may be associated with more pronounced interstitial involvement and bronchospasm,[14] whereas in patients with BA, a more uniform energy distribution may result from variability in bronchial obstruction, mucosal edema, and bronchospasm. In COPD, compared with the main group, energy distribution shifts toward lower-frequency components during the second phase of cough, which may be related to the presence of more viscous, difficult-to-expectorate sputum.

At the Department of Faculty Therapy of Voronezh State Medical University named after N.N. Burdenko, STFBG has been studied as a diagnostic method for COPD,[15] BA,[16] COVID-19,[16] and pneumonia.[17] Using STFBG, a characteristic cough sound pattern was identified in patients with COVID-19. For rapid diagnosis, a prognostic model based on a multiple regression equation was developed. In addition, the effectiveness of antitussive therapy for dry cough in COVID-19 was assessed using spectral analysis of cough sounds.[17]

In the late 1990s, researchers in the same department attempted to perform STFBG in patients with pneumonia; however, reproducible, diagnostically significant results were not obtained. This was likely due to the use of a more complex data-processing technique based on the discrete Fourier transform, which required powerful equipment that was not readily available at the time.

In recent years, there has been a growing trend toward increasing the number of studies aimed at diagnosing respiratory tract diseases using spectral analysis of cough sounds.

Porter et al.[18] developed an automated algorithm for analyzing cough sounds in various respiratory diseases, which can be integrated into smartphones that also serve as recording devices. The algorithm analyzed cough sounds in combination with five clinical symptoms, including fever, rhinorrhea, audible wheezing, hoarseness, and symptom duration. Mel-frequency cepstral coefficients (MFCCs) and non-Gaussian acoustic features were extracted from cough sounds, and a classifier was trained. Diagnostic accuracy improved when additional clinical parameters, such as respiratory rate, were included. The proposed methods enabled the diagnosis of pneumonia, with positive percent agreement of 87% and negative percent agreement of 85%.

Liao S. et al.[19] attempted to diagnose pneumonia and bronchitis in children using cough sound analysis based on CFCS. Cough sounds were recorded in 173 patients. Support vector machines (SVM) and long short-term memory (LSTM) neural networks were used to select diagnostically significant parameters and train the classifier. The sensitivity and specificity of the classifier for diagnosing pneumonia were 87.5% and 93.3%, respectively.These results suggest that the proposed CFCS-based classifier effectively diagnoses pneumonia via cough-sound analysis.

Despite the potential of these approaches, the studies have several significant limitations that hinder their practical implementation. The use of neural networks does not always allow the identification of specific parameters necessary for accurate diagnosis and differential diagnosis of diseases based on cough sounds. The need for subjective clinical assessment reduces the sensitivity of the proposed algorithms.

Our study provides new data on the potential of spectral analysis of cough sounds and its possible use as a reliable, noninvasive marker for diagnosing pneumonia. In the future, we plan to develop a prognostic model for pneumonia diagnosis based on data obtained using STFBG and to investigate its role in the dynamic assessment of the disease following treatment initiation.

Conclusion

Pneumonia is a global healthcare problem and one of the leading causes of death and hospitalization among respiratory diseases. Cough is among the most frequent complaints of patients seeking primary health care for respiratory diseases. Cough in patients with pneumonia demonstrates significant differences in key frequency–time characteristics compared with cough sounds in patients with BA, COPD, and COVID-19. These findings suggest that STFBG may be a useful tool for differential diagnosis of pneumonia.

Ethical Considerations

The study was approved by the Ethics Committee of Voronezh State Medical University named after N.N. Burdenko (Protocol #5 dated 21.10.2024). Written informed consent was obtained from all study individuals.

Author Contributions

Andrey V. Budnevsky: Conceptualization, Methodology, Formal Analysis, Writing – review & editing.
Sergey N. Avdeev: Conceptualization, Supervision, Validation, Visualization.
Evgeniy S. Ovsyannikov: Supervision, Project administration, Writing – review & editing.
Avag G. Kitoyan: Investigation, Data curation, Writing – original draft.
Sofia N. Feigelman: Investigation, Data curation, Writing – original draft.
All authors have approved the final article.

Conflict of Interest

The authors have declared no conflict of interest.

Disclaimer

Views expressed in the submitted article represent the opinions of the authors and not an official position of the universities or funder.

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