

Application of Acoustic Voice Analysis in the Diagnosis of Dysphonia in Parkinson's Disease

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Abstract The article examines the use of acoustic voice analysis for the early diagnosis of dysphonia in patients with Parkinson's disease (PD). The study involved 120 people who had both motor and non-motor indicators of vocal function assessed. The Heinemann hardware and software complex and the Ling Waves program (WEVOSYS) were used for data collection and analysis. The results showed statistically significant changes in the acoustic parameters of the voice in patients with PD compared with the control group. This confirms the reliability and effectiveness of this method for the early diagnosis of dysphonia in PD. In addition, the method can be used to assess the dynamics of the condition of patients with this pathology.

Keywords Parkinson's disease, Dysphonia, Acoustic voice analysis, Motor parameters of acoustic voice analysis, Non-motor parameters of acoustic voice analysis, Early diagnosis, HEINEMANN software and hardware complex, Ling Waves, Dysphonia index

1. Introduction

The main information carriers for humans are signals that are formed by the senses, delivered to the brain, and processed there. These are the voice's acoustic speech signals, first and foremost. Voice is the term used to describe the sounds made by air exhalation, vocal cord vibrations, and resonance systems. Here, the vocal folds (VFs) work in tandem with resonator devices to regulate the airflow exclusively. As is well known, the central (regulatory) and peripheral (executive) components of the speech apparatus are interrelated. The peripheral part of the speech apparatus consists of organs, muscles, ligaments, motor muscles and, sensory nerves, as well as bones and, cartilaginous tissues, bone and cartilaginous tissues. Make up the peripheral part of the speech apparatus.

Cerebral cortex, the central region consists of the cortex, subcortical nodes, pathways and associated nerve nuclei include the central region. Breathing is the basis of speech.

Exhalation - when this speech formation is formed, since the air flow performs articulatory and voice-forming functions. Since the air flow performs articulatory and voice-forming tasks. Vocal cords ligaments close, reproducing the voice. Close to making a voice. They open when exhaling, breathing.

Released. They have a tendency to return to their original position due to the activity of the laryngeal muscles and the elasticity of the vocal cords. to their original position due to the activity of the laryngeal muscles and the elasticity of the vocal folds. The alternate convergence and divergence of the vocal cords is maintained by a constant pressure of exhaled air and divergence are maintained by a constant pressure of exhaled air. The convergence and divergence in the transverse direction will continue as long as the pressure of exhaled air flow is in effect. The vibrations transform the exhaled air into the movement of air particles above the vocal cords. These vibrations are transmitted to the environment and are perceived as vocal sounds. Breathing during speech differs from normal breathing. When speaking, the exhalation is significantly longer than the inhalation (under normal conditions, their duration is approximately the same). The duration ratio is about 1:8. The frequency of respiratory movements during speech also decreases by half. The inhalation phase becomes active and controllable. Long speech requires a large supply of air, so the volume of inhaled and exhaled air increases. Duration and depth are regulated by the active participation of the abdominal wall muscles and internal intercostal muscles. Muscle innervation is carried out by the thoracic and cervical spinal nerves, as well as the vagus nerve. Subcortical structures and areas of the cerebral cortex participate in the control of speech breathing. The voice formation system involves systems such as: upper and lower respiratory tracts, diaphragm, abdominal press, larynx, GS, pharynx, oral cavity, nasal cavity

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and its accessory sinuses, and final elements of the nervous system that conduct and transmit signals connecting voice formation organs with brain centers. In stages, the sound formation process occurs through:

- Due to the flow exhaling from the lungs, a sound is formed.
- A stream of air moves the vocal cords.
- Voice pitch is predetermined by the length and tension of the GS.
- The strength of the voice is predetermined by the closure density and air pressure.
- The degree of GC tension changes when the internal muscles of the larynx contract.
- The position of the GC depends on the displacement of the cartilages to which it is attached, i.e., to the arytenoid and thyroid cartilages.
- The position of the tongue, lips, soft and hard palate in the oral cavity determines its shape, which determines the production of a particular sound.

The human voice showcases the most diverse spectrum of motor actions compared to any other human endeavor. Nevertheless, the clinical examination of vocal characteristics in individuals affected by motor impairments, like Parkinson's disease (PD), has not kept pace with current scientific understanding. Symptoms of Parkinson's disease (PD), due to the disease, can vary greatly. Parkinson's disease (PD) is a neurological disorder that can manifest itself in a variety of ways. Many large bodies of research show that decreased dopamine signaling in the nigrostriatal pathways plays a critical role in the onset of Parkinson's disease. indicates that decreased dopamine signaling in the nigrostriatal pathways plays a critical role in the onset of Parkinson's disease. The characteristic motor profile, characterized by a decrease in the amplitude of movements, a delay in their execution and a decrease in automaticity, is ultimately the result of a disruption of neural processes in the basal ganglia and associated circuits responsible for the regulation of movements. The profile, characterized by a decrease in the amplitude of movements, a delay in the execution of movements and a decrease in automaticity, is ultimately the result of a disruption of neural processes in the basal ganglia and associated circuits responsible for the regulation of movement.

Among the over seven million individuals globally diagnosed with Parkinson's disease, a substantial 75%-90% experience voice and speech difficulties during the progression of the condition. Consequently, voice and speech represent a highly relevant "motor behavior" that is often underutilized in clinical evaluation and treatment strategies. Analyzing speech through sophisticated data analysis techniques can significantly contribute to the assessment of PD, enabling insights into treatment effectiveness and facilitating tailored patient care.

The procedure for diagnosing Parkinson's disease is currently not very well-developed. Diagnosis includes a number of methods, including identifying and assessing symptoms, conducting clinical trials, and using laboratory

tests. 70% to 90% of patients with Parkinson's disease (PD) exhibit a modified voice [5]. Various studies have shown that voice and prosody are among the earliest indicators of BP. Lack of muscle function is very characteristic of the voice. People with PD tend to speak incoherently, stopping often while talking, have a strained, hoarse voice, and have poor pronunciation. When talking, speak in a strained, hoarse voice and have poor pronunciation. Patients usually lose the natural intonation of natural speech, causing the voice and tone to change and become more monotonous. intonation, causing the voice and tone to change and become more monotonous. Bradykinesia, or slowing of movements, is the main primary symptom of Parkinson's disease (PD) Parkinson's disease (PD) sometimes also has slower speech. However, BP can usually have a faster, more rapid speech, which is very characteristic. We also see accelerated movements, especially when walking, which are called fast walking or talking. fast, rapid speech, which is quite characteristic. We also see accelerated movements, especially when walking, which are called fast walking or talking. is actually quite unusual. A typical patient speaks quietly (hypophonically), hoarsely/tensionfully and, interestingly, has characteristic accelerated speech, i.e., a faster manner of speaking. PE patients can maintain a good quality of life with proper medical care. Recognizing early signs and seeking medical attention in a timely fashion is crucial for better disease management. In addition to the complexity of PD, it is recognized that the disease manifests in both rapid and slowly progressive forms, illustrating the heterogeneous nature of PD. Thus, speech is a very suitable "motor behavior" that is poorly represented in clinical assessment and decision-making.

Currently, there is a deep interest in the quantitative assessment of the condition in PD. Because there is no clinically detailed expert evaluation. Early detection of diseases is one of the key factors in the success of their treatment, especially in cases involving socially significant organs. Acoustic analysis (AAS) is an objective, non-invasive method for assessing voice quality in patients with both BP and other voice disorders.

2. Purpose of the Study

Using acoustic analysis of the voice (AAG), to identify the most significant acoustic parameters reflecting the harmonic and noise components of the spectrum of voice disorders in patients with Parkinson's disease (PD). The task is to compare the acoustic characteristics of the voice in PD patients at different stages of the disease. Based on statistical processing of the results obtained using the Ling Waves software, to determine pathognomonic voice markers using AAG.

3. Materials and Methods

The methodology for examining the larynx and voice function included the following stages. Initially, a phoniatriest examined the larynx and assessed the vibratory cycle

indicators using rigid endoscopes and a video laryngostroboscope (XION). Acoustic examination of patients included objective (computer) sound analysis using the HEINEMANN hardware and software complex and the Ling Waves (LW) program (WEVOSYS). To ensure an accurate assessment of sound quality, the study was conducted in a specially equipped room with a noise level of no more than 30 dB. The microphone was placed 30 cm away from the patient's mouth. Each examinee was required to complete a certain number of simple test tasks. In LW software, there are several types of examinations, such as **VDS** - VOICE DIAGNOSTIC CENTER (voice diagnostic center), **VLT** - Voice load test, **SPR** - real-time spectrography, **MRT** - real-time multi-mode display, **VDI** - voice disorder index, **VOS** - spectrometry, **MSD** - assessment of motor speech disorders, and others. Each type of analysis includes several variations of test tasks. To detect voice and speech disorders in patients with BP, it was decided to conduct analyses:



Figure 1. Voice Recording Technique

VDS - Voice Diagnostics Center. The voice diagnostics center is designed for the combined quantitative and qualitative analysis of the voice. It provides the ability to review and document various voice parameters. This analysis is carried out at the highest technological level. The quantitative indicators of the voice are measured through a modern

standardized procedure - phonetography (singing and speech profiles). **1. 1.** Phonetogram - sound quality. Here, parameters such as frequency of occurrence, dynamic range of tonality, dynamics of volume, and normal profile coverage are considered. To assess the state of the speech apparatus in patients with PD, it was decided to compare the results of the conversation profile test. Using the conversation profile, it is possible to determine the average range of the patient's voice for normal, quiet (relaxed) and loud (tensioned) modes of conversation. For this, the subject asks the subject to count different regimes separately from 21 to 40. In this case, the program mathematically automatically calculates the average frequency of tonality and volume. For the research, we took the frequency range indicator. **2.** Then the conversation curve was calculated. The task was to shout "Hey, Tanya, come to me" separately, stretching the words - for the Russian-speaking population and "Hey, Vali, come to my side!" - for the Uzbek-speaking contingent of the subjects. At the same time, the slope of the conversation curve is displayed on the display as a straight line, showing how quickly the tonality increases when the volume is increased. A good voice is characterized by a sharp increase in the speech curve greater than 1. In healthy individuals, the conversational profile of normal, quiet, and loud vocal modes is located in the area from the lower to the middle third of the singing profile. The scream level should exceed 90 dB and be between the head and chest registers of the singing profile. For reliable screaming registration, each patient was demonstrated how to scream.

The second indicator for which diagnostic analysis was planned was Vospector. To assess the degree of dysphonia, the DSI index was chosen, developed by Marc S. de Bodt and Floris L. Wuyts from the University of Antwerp as an objective quantitative indicator of voice quality. It combines several voice parameters into a single weighted combination, including four characteristics: maximum phonation time (MPT, s), highest frequency (F0-high, Hz), low intensity (I-low, dB (A)) and vibration (%).

$$\text{DSI} = 0.13 * \text{MRT} + 0.0053 * \text{F0-high} - 0.26 * \text{I-low} - 1.18 * \text{jitter} + 12.4$$

is the formula used to perform the calculation.

All votes are categorized into six groups based on the severity of the anomalies using the DSI index (see Table 1) based on the severity of the anomalies using the DSI index (Table 1).

Table 1

Group	DSI range	Description
0	<-2.0	Severe persistent aphonia: voice absent, inability to pronounce
1.	From -1.9 to + 0.3	Constant dysphonia: occasional periods of phonation, possible periods of aphonia
2.	From +0.4 to +2.2	Moderate dysphonia: Voice formation is possible, however, frequent periods of dysphonia are noted.
3.	From +2.3 to +3.3	Mild and moderate dysphonia: less frequent phony disorders or mild persistent dysphonia
4.	From + 3.4 to + 4.3	Mild dysphonia: occasional brief episodes of dysphonia
5.	> 4.4	Absence of dysphonia

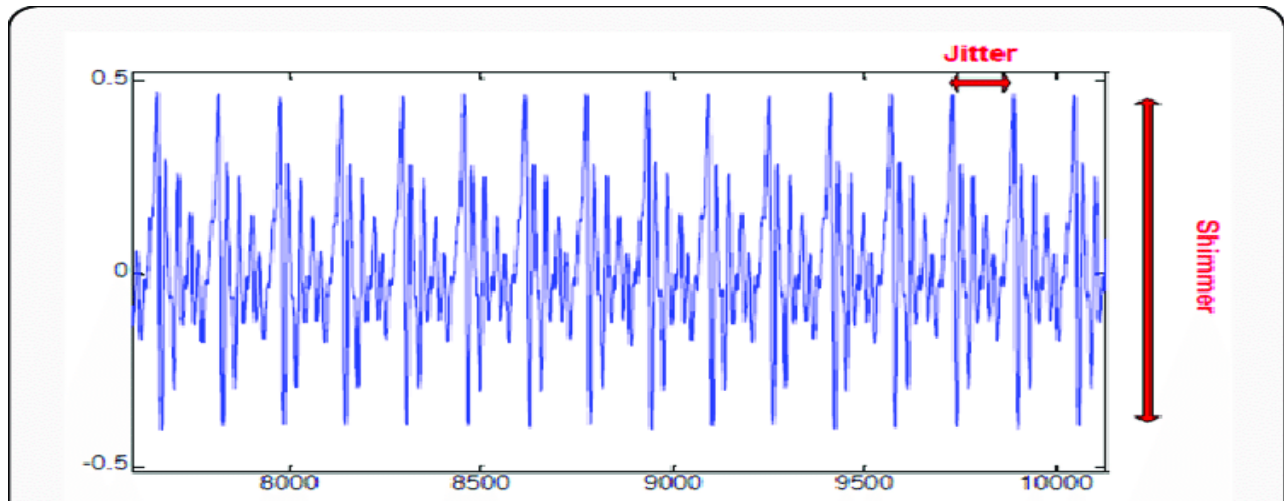


Figure 2. Visual representation of jitter and shimmer measures in a speech signal

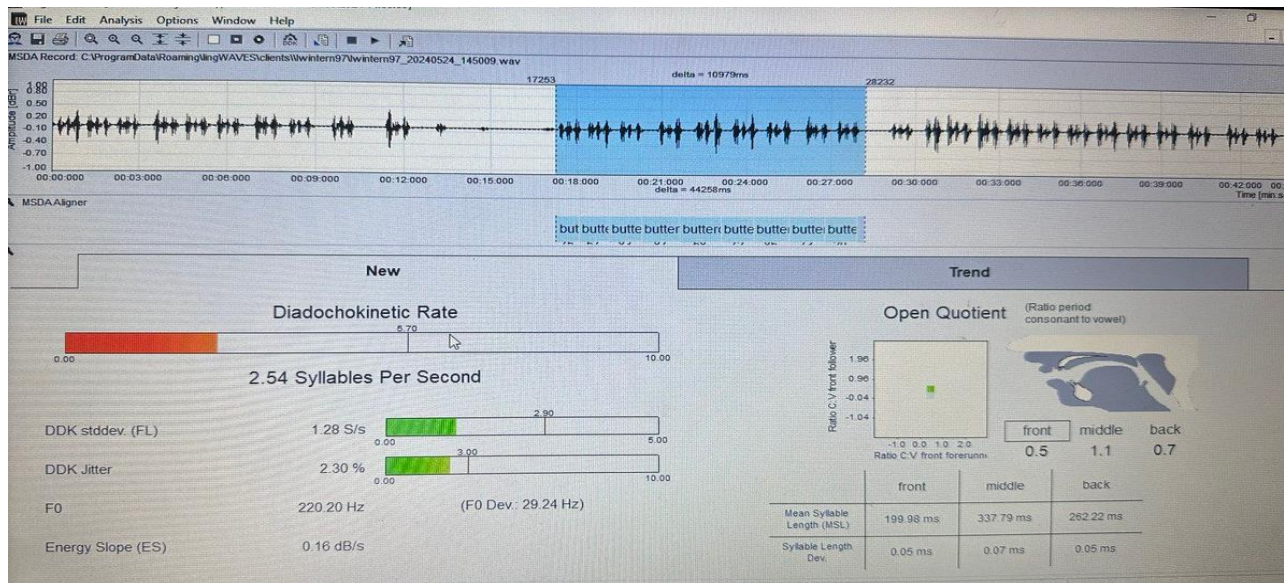


Figure 3. Graphical representation of recorded sounds and numerical values of the voice

The DSI classification by LW VOSPECTOR differs slightly from the information provided by Marc S. de Bodt and Floris L. Wuyts. DSI differs slightly from the information provided by Marc S. de Bodt and Floris L. Wuyts.

LW uses a new clinically tested vibration algorithm with higher mean values.

To calculate the index of voice disturbance, the patient is asked to pronounce a vowel, for example [a], in a comfortable tone for a long time (5 seconds). The maximum phonation time of the same vowel letter is also measured, and then the most suitable part of the recording is selected with the cursor.

4.5. Next, the program itself calculates the severity index of dysphonia, as well as the Shimmer (flashing) and Jitter (shaking) indicators. A jitter is defined as the parameter of frequency change from cycle to cycle, while flickering refers to the change in sound wave amplitude. These parameters can be analyzed using the example of a smooth voice that continuously pronounces vowel sounds. Voice jitter is caused mainly by loss of control over the vibration of the

ligaments. Patients with various pathologies often have an increased level of jitter in the voice. In most studies, a deviation of 0.5% to 1.0% is considered a normal indicator of stable phonation in young people. Voice instability increases as the resistance of the glottis decreases and with the formation of volumetric lesions of the vocal cords, which is associated with the appearance of noise and breathing in the voice. Jitter values exceeding 5.0% in adults are considered a sign of a pathological condition of the voice.

II. The next analysis considered in the examination to assess the state of voice and speech in patients with PD was MSDA- assessment of motor speech disorders. Motor disorders are called "dysarthria" or "apraxia." As a result of stroke or craniocerebral trauma or other neurodegenerative disorders such as CP, oral muscles and other voice-forming structures may weaken, leading to slowed articulatory movements and consequently, impaired sequential pronunciation of sounds and syllables in words. Maximum speech speed can be determined using the diadochokinetic index (DDK).

The Motor Speech Impairment Assessment System (MDSA) used in LW allows for the detection of DDK in seconds. In this case, the sequentially pronounced word "baterkap" is recorded during one exhalation, i.e., on one airflow. A few seconds after the automatic calculation begins, the results window (left) displays normal (green) and pathological (red) DDK values, as well as other MDSA parameters (scattering and standard deviation, energy gradient, F0).

6. Diadochokinetic velocity (DDK) in syllables per second (C/s). The correspondence of DDK to normal values (5.7 C/s) is displayed by color coding and in numerical expression.

7. DDK stddev (standard deviation in C/s): DDK stddev reflects the uniformity of word pronunciation. If all words are pronounced accurately and at the same speed, then this indicator is zero (but this is never the case) and the normal value should be 2.9 C/s. Large values indicate significant differences in the speed of articulation - impaired speech motor skills.

8. The DDK (%) dispersion is calculated based on the cyclical variability of syllable length. To calculate the DDK scattering, at least 5 repetitions of the word "baterkap" are required. The normal value is less than 3%. Large values indicate significant differences in the speed of articulation - impaired speech motor skills.

9. F0 (basic frequency in Hz). Calculation of the patient's main voice frequency. Results depend on gender and age (children). Sex differences: Men and women have different basal frequency ranges. In men, it is lower and amounts to approximately 100-150 Hz. In healthy women, F0 is in the range of 180-250 Hz. In childhood, the basal frequency (BF) is higher due to the smaller size of the vocal cords. With age, VO decreases in both sexes, especially after puberty. Towards old age, a further decrease in WC is observed. In healthy individuals, the HR is stable and within these values, demonstrating normal HR control and a stable voice pitch.

10. Energy gradient (in dB/s) is a new method for measuring energy loss when pronouncing a sequence of words. In a healthy person, energy losses are absent or minimal (close to 0). Higher negative values indicate significant expiratory and/or vocal fatigue during the conversation.

From January 2023 to April 2024, a WEVOSYS acoustic analysis of the voice was conducted using the LW software with a diagnosis made by a neurologist with PD. 120 participants who were fluent in Russian and Uzbek languages and had no inflammatory pathologies of the vocal apparatus were examined. One hundred participants in the survey were patients with Parkinson's disease and 20 were healthy. We divided patients with Parkinson's disease into 3 groups according to the duration of the disease: 1-group - duration of the disease up to 5 years, 2-group - from 5 to 10 years, 3-group - duration of the disease more than 10 years. Also, patients from each group were further divided into 4 subgroups by age: 1-subgroup 70-80 years old, 2-subgroup 61-70 years old, 3-subgroup 51-60 years old, 4-subgroup 41-50 years old.

4. Results and Their Discussions

In the table of the dysphonia severity index (spectrum) (table No2), significant differences are indicated compared to the healthy group. In patients with a history of Parkinson's disease up to 5 years, the values begin to deviate from the healthy norm, especially in the 61-70 and 41-50 age groups by 0.99 and 1.42 respectively ($p < 0.001$), which indicates the initial signs of dysphonia. In patients with a disease history of 5 to 10 years in the age group of 71-80 years, this indicator was significantly lower by 1.96 compared to the healthy group ($p < 0.001$). This indicates more pronounced vocal dysfunction as the disease progresses.

Table 2. Dysphonia severity index in patients with Parkinson's disease (Vos spectrometry)

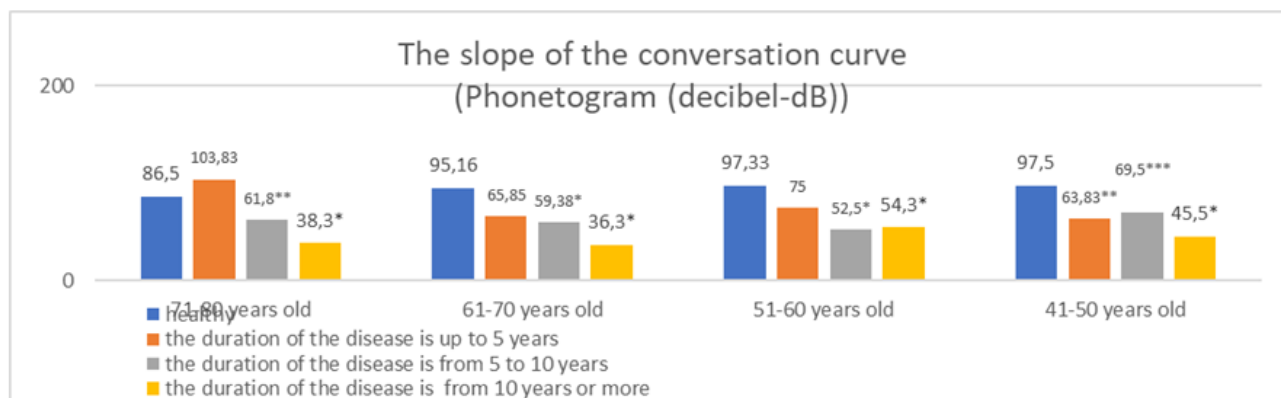
Age \ Long-lasting	Healthy	Disease duration up to 5 years	Disease duration from 5 to 10 years	Disease duration from 10 years and above
71-80 years	4.3±0.16	4.06±0.28	2.34±0.25*	0.97±0.4*
61-70 years old	4.61±0.14	3.62±0.17*	2.52±0.23*	1.32±0.16*
51-60 years old	4.66±0.07	4.34±0.29	2.82±0.16*	1.96±0.08*
41-50 years old	4.95±0.14	3.53±0.28*	3.15±0.18*	1.33±0.22*

Note: *- significance compared to the healthy group $p < 0.001$.

Table 3. Changes in the frequency range of voice in patients with Parkinson's disease (Phonetogram, (Hz))

Age \ Duration of b-ni	Healthy (Hz)	Duration of disease up to 5 years (Hz)	Duration of disease 5-10 years (Hz)	Duration of illness from 10 years and above (Hz)
71-80 years	106.62±5.48	279.87±10.66*	226.6±7.72*	115.46±15.18
61-70 years old	141.58±8.71	264.67±14.40*	218.45±17.2*	150.25±12.
51-60 years old	151.5±7.52	264.6±17.14*	149.66±10.84	172.82±6.92**
41-50 years old	140.48±13.78	256.08±11.71*	215.61±18.59***	118.62±10.18

Note: *- significance compared to the healthy group $P < 0.001$; ** - $P < 0.05$; *** - $P < 0.01$.



Note: *- significance compared to the healthy group; P < 0.001; ** - P < 0.05; *** - P < 0.01.

Diagram 1

The most pronounced deviations from the norm are observed in patients with more than 10 years of experience. For example, in the 71-80 age group, the dysphonia index value is 0.97 ± 0.4 , which is significantly lower than the indicator of the healthy group by 3.33 ($p < 0.001$), indicating serious vocal dysfunction.

Observations of frequency range changes in patients with disease history up to 5 years in all age groups revealed significant deviations from the norm by 173.25 Hz; 123.09 Hz; 113.1 Hz and 115.6 Hz respectively with age ($P < 0.001$). In the 71-80 age group with 5-10 years of disease history, this value is 226.6 ± 7.72 Hz, which indicates a 120 Hz decrease in the frequency range compared to the healthy group ($P < 0.001$). In the group with a disease history of more than 10 years, the closest values of the frequency range to the indicators of healthy individuals are observed ($P < 0.001$).

These calculations show that in the group of patients with Parkinson's disease with up to 5 years of experience, the most significant differences in frequency range from healthy individuals are observed, especially in older age categories, which may be associated with the body's compensatory mechanisms.

Diagram.1. shows that in patients with a disease history of up to 5 years, compared to the healthy group, the slope of the speech curve begins to decrease, especially in the 41-50 age group, which indicates early manifestations of changes in vocal function. The slope values of the conversational curve decrease even further, especially in the age group of 71-80 years (61.8 ± 10.69 dB) with a disease history from 5 to 10 years, which indicates a progressive deterioration. The lowest values of the slope of the speech curve are observed in patients with more than 10 years of experience, especially in the age groups of 71-80 years (38.3 ± 6.12 dB) and 61-70 years (36.3 ± 5.4 dB) ($P < 0.001$), respectively, by 48.2 dB and 58.86 dB, which is associated with impaired coordination of the vocal muscles, rigidity, respiratory restriction, and monotony of speech, which is a consequence of progressive changes in the nervous system in Parkinson's disease.

The Shimmer parameter represents the amplitude fluctuations of the voice and its increase, indicating the instability of the voice function. Table 4 shows that patients

with a disease history of up to 5 years slightly exceed the indicators of the healthy group, especially in the 61-70 (15.14 ± 2.22) and 41-50 (13.89 ± 1.54) age groups, by approximately 7% in both subgroups, indicating the initial signs of voice instability. The highest Shimmer values are observed in patients with more than 10 years of experience, for example, in the 71-80 age group (16.16 ± 1.5) and 61-70 age group (15.65 ± 1.78), a deviation from the indicators of healthy individuals is almost 2 times greater, which indicates pronounced disorders of vocal function ($P < 0.001$). This indicates pronounced vocal instability disorders associated with impaired vocal muscle coordination, rigidity, tremor, and respiratory disturbances characteristic of Parkinson's disease.

The Jitter parameter reflects voice frequency instability, and its increase indicates a violation of voice function. In patients with a disease history of up to 5 years in the 61-70 age group, the Jitter values begin to exceed the indicators of the healthy group by 0.42% ($P < 0.001$). This indicates the initial manifestations of voice frequency instability. The Jitter score is even higher in the 51-60 age group with 5 to 10 years of disease experience compared to healthy individuals of the corresponding age group by 0.46% ($P < 0.001$). The highest Jitter values are observed in patients with more than 10 years of experience, for example, in the 71-80 age group (0.81 ± 0.09 , $P < 0.05$), which indicates pronounced frequency stability disorders of voice caused by voice muscle coordination disorders, rigidity, tremor, and respiratory problems, which are characteristic symptoms of Parkinson's disease.

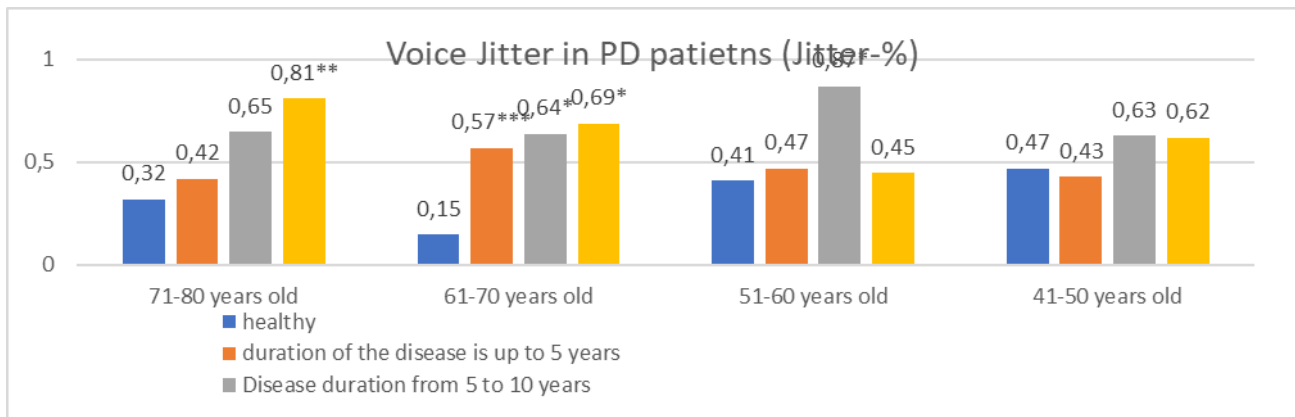
Diadochokinesis (DDK) reflects the ability to rapidly alternate muscle movements, which is important for speech function. In the group of patients with a disease history of up to 5 years, the HDD is slightly lower in all age groups than in healthy individuals ($P < 0.001$). This indicates initial disruptions in the coordination of speech movements. HDD values continue to decrease in patients with 5 to 10 years of experience. Especially in the 71-80 age group (3.87 ± 0.37), which is 2.63 C/s lower compared to the same age group ($P < 0.001$), indicating an increase in diadochokinesis disorders. The lowest HDD values are observed in patients with more than 10 years of experience, for example, in the

age group of 71-80 years by 3.78 S/s and 61-70 years by 4.92 S/s less compared to the healthy group (P<0.001). This indicates serious impairments in the ability to quickly change movements and significant deviations from normal values.

Table 4. Changes in vocal fremitus in patients with Parkinson's disease (Shimmer, (%))

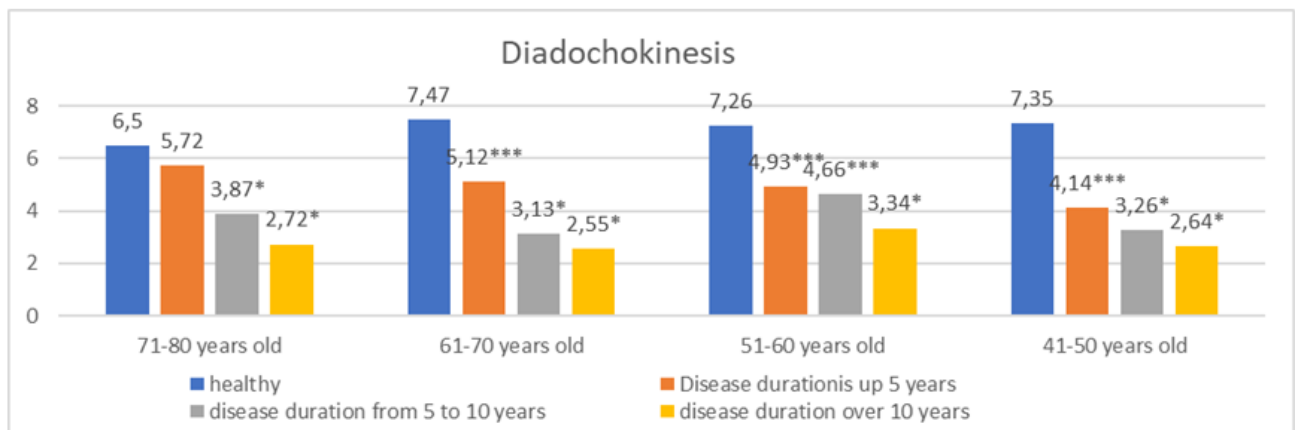
Age \ Duration of illness	healthy	Disease duration up to 5 years	Disease duration from 5 to 10 years	Disease duration over 10 years
71-80 years old	8.51±0.85	7.85±0.48	9.26±0.77	16.16±1.5*
61-70 years old	8.16±0.3	15.14±2.22***	12.1±1.33***	15.65±1.78*
51-60 years old	7.76±0.52	10.88±1.81	17.37±0.81*	12.86±1.21*
41-50 years old	7.29±0.43	13.89±1.54*	7.56±0.28	13.91±0.92*

Note: *- significance compared to the healthy group P <0.001; ** - P<0.05; *** - P<0.01.



Note: *- significance compared to the healthy group P <0.001; ** - P<0.05; *** - P<0.01.

Diagram 2



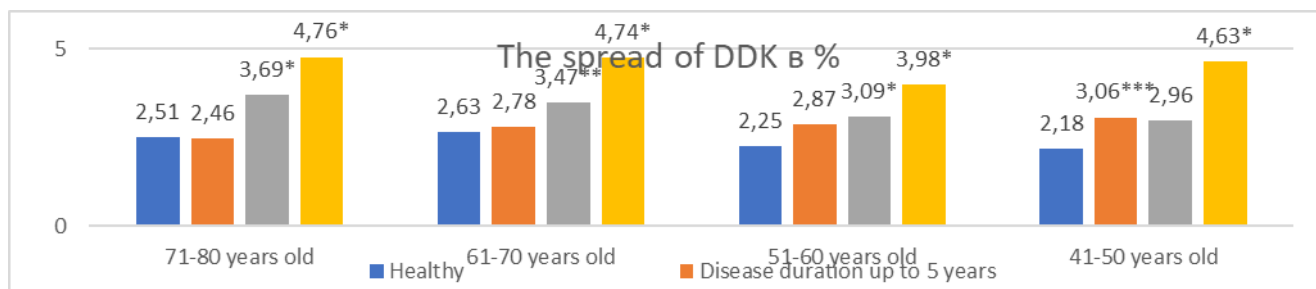
Note: *- significance compared to the healthy group P <0.001; ** - P<0.05; *** - P<0.01.

Diagram 3. Changes in diadochokinesis in patients with Parkinson's disease (syllable/second-C/c)

Table 5. Changes in the standard deviation of word pronunciation per second in patients with Parkinson's disease (words/sec)

Age \ Duration of illness	Healthy	Disease duration up to 5 years	Disease duration from 5 to 10 years	Disease duration over 10 years
71-80 years	2.78±0.11	2.16±0.4	3.37±0.17***	3.95±0.21*
61-70 years old	2.68±0.13	2.26±0.29	3.32±0.18***	4.11±0.21*
51-60 years old	2.13±0.2	2.36±0.24	4.07±0.22*	3.29±0.27*
41-50 years old	1.83±0.24	2.11±0.31	2.42±0.24	4.03±0.39*

Note: *- significance compared to the healthy group P <0.001; ** - P<0.05; *** - P<0.01.



Note: *- significance compared to the healthy group P <0.001; ** - P<0.05; *** - P<0.01.

Diagram 4

Table 6. Changes in baseline frequency in patients with Parkinson's disease (Hz)

Age \ Duration of illness	Healthy	Disease duration up to 5 years	Disease duration from 5 to 10 years	Disease duration over 10 years
71-80 years	126.83 ±6.88	161.18 ±21.58	139.57 ±1.57	114.02 ±1.04
61-70 years old	135.94 ±9.43	222.16 ±17.61*	154.15 ±1.62	149.51 ±6.37
51-60 years old	157.04 ±4.67	151.1 ±1.31	126.2 ±13.48**	135.05 ±2.51
41-50 years old	147.73 ±12.91	184.06 ±25.25	173.83 ±4.31	109.78 ±6.26***

Note: *- significance compared to the healthy group P <0.001; ** - P<0.05; *** - P<0.01.

Table 7. Changes in energy gradient in patients with Parkinson's disease (dB/sec)

Age \ Duration of illness	Healthy	Disease duration up to 5 years	Disease duration from 5 to 10 years	Disease duration of 10 years or more
71-80 years	0.02 ±0.29	-0.32 ±0.17	-0.11 ±0.32	-1.95 ±0.29*
61-70 years old	1.10 ±0.22	-0.26 ±0.14*	-0.7 ±0.21*	-1.33 ±0.2*
51-60 years old	0.14 ±0.19	-0.09 ±0.06	-0.47 ±0.27	-0.61 ±0.11*
41-50 years old	0.09 ±0.18	-0.34 ±0.17	-0.2 ±0.2	-0.77 ±0.19***

Note: *- significance compared to the healthy group P <0.001; ** - P<0.05; *** - P<0.01.

The standard deviation of word pronunciation per second reflects the variability of speech speed and the stability of rhythm, which is important for normal speech function.

Patients with Parkinson's disease with a disease history of up to 5 years demonstrated standard deviation values close to those of healthy individuals, indicating relatively small changes in speech stability in the early stages of the disease. In patients with 5 to 10 years of experience, the standard deviation values increase significantly, especially in the 51-60 age group (4.07 ±0.22), almost 2 times more than in the healthy group of the same age group (P<0.001), which indicates increasing speech instability and increased variability in the speed of word pronunciation. The highest values of the standard deviation are observed in patients with more than 10 years of experience, for example, in the 61-70 (4.11 ±0.21) and 71-80 (3.95 ±0.21) age groups, respectively, by 1.43 words/sec and 1.17 words/sec more than in the healthy group (P<0.001), which indicates pronounced disorders of rhythm and speech stability.

Changes in DDK distribution in patients with Parkinson's disease (%)

Patients with Parkinson's disease with up to 5 years of experience have slightly higher HDD scatter values in % compared to healthy individuals, for example, in the 41-50 age group (3.06 ±0.26) (P<0.001). This indicates initial

disruptions in the stability of speech movements. DDT scatter values in % continue to increase with disease duration. As in patients with 5 to 10 years of experience in the age groups of 71-80 years (3.69 ±0.8) and 51-60 years (3.09 ±0.08), it was 1.18% and 0.84% higher, respectively, compared to the healthy group (P<0.001), which indicates an increasing instability of rhythm and movement coordination. The highest values of DDC dispersion in % are observed in patients with more than 10 years of experience, for example, in the age group of 71-80 years (4.76 ±0.26) and 61-70 years (4.74 ±0.43), approximately 2 times more than in healthy individuals of the corresponding group (P<0.001). This indicates pronounced disorders of speech stability and rhythm, impaired coordination and stability of articulatory movements, which is associated with progressive deterioration of motor control.

In the 61-70 age group, with a disease duration of up to 5 years, a significant increase in the basal frequency of 86.22 Hz is observed in patients with Parkinson's disease in its early stages, which may be associated with increased vocal cord tension due to rigidity, leading to an increase in voice pitch. (P<0.001). In the 51-60 age group, with a disease duration of 5 to 10 years, a significant decrease in the main frequency by 30.84 Hz (P<0.05) is observed. This may be due to the progressive disruption of control over the laryngeal muscles and a decrease in the flexibility of the vocal cords,

resulting in a lower basal frequency. Significant decrease in the main frequency in patients with long-term medical history, indicating serious impairments in vocal function. In the age group with more than 10 years of work experience, the main frequency value is 37.95 Hz lower compared to the healthy group. Perhaps this is due to pronounced rigidity and tremor of the vocal cords, as well as deterioration of respiratory support, which leads to a decrease in the pitch of the voice.

In the 61-70 age group, with a disease duration of up to 5 years, a significant decrease in the energy gradient of 0.84 dB/sec compared to healthy individuals is observed, which may be related to early disorders in controlling voice strength and speech energy ($P < 0.001$). In patients with a disease history of more than 10 years in the age group of 71-80 years, a decrease in the energy gradient by 1.97 dB/sec compared to the healthy group ($P < 0.001$) is revealed, which indicates serious disorders in voice control and a decrease in the ability to vary the strength of sound.

The energy gradient table shows that in patients with Parkinson's disease, especially with a disease duration of more than 10 years, there is a significant decrease in the energy gradient compared to healthy individuals. This is due to pronounced disorders in controlling voice intensity, muscle rigidity and hypokinesia, respiratory support problems, and tremor, which leads to a decrease in the dynamism and variability of voice strength.

5. Conclusions

Acoustic analysis of the voice in patients with Parkinson's disease reveals significant changes in a number of key parameters, such as frequency, slope of the speech curve, energy gradient index, and other characteristics. The analysis showed that:

1. Voice frequency: In patients with Parkinson's disease, deviations in the frequency characteristics of the voice are observed, depending on the stage of the disease. In the early stages, the frequency may be higher than

normal, while in the late stages it significantly decreases, indicating a loss of control over the voice and monotony.

2. Energy gradient: As Parkinson's disease progresses, a decrease in the energy gradient of the voice is observed, manifested in a decrease in amplitude and stability. This reflects the decrease in the ability to control the volume of the voice, characteristic of the late stages of the disease.
3. The slope of the conversational curve: healthy individuals retain a high slope, while in patients with Parkinson's disease, the slope decreases as the duration of the illness increases. This is due to a violation of voice modulation and weak muscle control.

These indicators demonstrate progressive changes in the vocal apparatus in patients with Parkinson's disease, which can be used to diagnose, determine the stage of the disease, and monitor its progression.

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