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Effects of Subthalamic Nucleus Deep Brain Stimulation Surgery on Voice and Formant Frequencies of Vowels in Turkish

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ABSTRACT

AIM: To investigate the effects of deep brain stimulation (DBS) of the subthalamic nucleus (STN) on acoustic characteristics of voice production in Turkish patients with Parkinson's disease (PD).

MATERIAL and METHODS: This study recruited 20 patients diagnosed with PD. Voice samples were recorded under the "stimulation on" and "stimulation off" conditions of STN-DBS. Acoustic recordings of the patients were made during the production of vowels /a/, /o/, and /i/ and repetition of the syllables /pa/-/ta/-/ka/. Acoustic analyses were performed using Praat.

RESULTS: A significant difference in the parameters was observed among groups for vowels. A positive significant difference was observed between preoperative med-on and postoperative med-on/stim-on groups for /a/ and the postoperative med-on/stim-on and postoperative med-on/stim-off groups for /o/ and /i/ for frequency perturbation (jitter) and noise-to-harmonics ratio. No significant difference was noted between the preoperative med-on and postoperative med-on/stim-off groups for any vowels.

CONCLUSION: STN-DBS surgery has an acute positive effect on voice. Studies on formant frequency analysis in STN-DBS may be expanded with both articulation and intelligibility tests to enable us to combine patient abilities in various perspectives and to obtain precise results.

KEYWORDS: Acoustic, Deep brain stimulation, Parkinson's disease, Subthalamic nucleus, voice

INTRODUCTION

Parkinson's disease (PD) is a neurodegenerative disease due to the progressive loss of dopaminergic neurons in the midbrain. Typical clinical symptoms include tremors, postural instability, rigidity, and bradykinesia (5,27). In most patients with PD, phonation, prosody, and the phonological aspects of speech are impaired due to hypokinetic dysarthria. These patients also present with a change in the voice quality. The voice of these patients may sound breathy, strained, or raspy. This changed voice quality, hypophonia, low speed and intensity are common deficits noted in patients with PD. Harsh voice quality is a common presentation of patients with all types of dysarthria, and this has been frequently reported in patients with PD as well (22). This presentation results from the patient's inability to control voice pitch during phonation because of the impaired vocal fold vibration. The voice of medically treated patients with PD have been reported as monopitch, breathy, and harsh (6). As the standard deviation of the fundamental frequency value is reduced, monopitch voice is also noted in hypokinetic dysarthria in patients with PD (19).

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Laryngoscopic findings have been described as an incomplete glottal closure, asymmetrical vocal fold movement, supraglottic contraction, laryngeal hyperfunction, and laryngeal tremor (8,24).

Deep brain stimulation (DBS) of the subthalamic nucleus (STN) is an effective treatment method for reducing motor symptoms in patients with PD (17). However, the effects of STN-DBS on speech changes primarily because of the patient characteristics, and these effects are deteriorated mainly because of the presence of dysarthria and the progression of PD (4). Vowel production and formant frequency analysis in patients with PD are the indicators of speech intelligibility. Limited studies on formant frequency varies in stimulation (13), medication (16), or both (29). Instrumental analysis is a common method used to define the voice of patients undergoing STN-DBS. Both negative and positive effects on voice were reported (15,29).

Evaluating the effects of STN-DBS on speech and voice using a multidimensional method may help assess the interaction of the processes involved in phonation. Accordingly, this study aimed to objectively evaluate the effects of STN-DBS on voice and the acoustic characteristics of vowel production in Turkish patients with PD.

MATERIAL and METHODS

Patients

Patients diagnosed with PD were prospectively recruited in the study. All patients underwent STN-DBS surgery. The inclusion criteria were as follows: patients without any other neurological deficits, hearing loss, or morphological abnormalities of the larynx and vocal tract. Laryngeal examinations were performed by an otolaryngologist before the acoustic measurement protocol was revealed. None of the patients had undergone speech or voice therapy at any time in their life, and the patients had no history of speech, language, or hearing pathologies. All patients could follow the instructions provided and were monolingual: Turkish was their first language. Each patient signed an informed consent form according to the protocols approved by the ethics committee of our university. Table I presents the demographics of the patients.

Procedure

Voice samples of the patients were recorded before and a month after surgery. Two sessions were conducted. In the first session, personal and clinical information of the patients as well as voice recordings were collected. The second session was held 1 month after surgery, and the same voice-recording protocol was repeated for the STN-DBS “on” and “off” conditions. All recordings were made in the “medication on” (med-on) condition.

Surgical Technique

Surgical targeting was typically performed a day before surgery using magnetic resonance (MR) images. High-resolution T2-weighted (slice thickness 2 mm without gap) and T1-weighted (slice thickness 1 mm without gap) contrast-enhanced MR images were obtained (3 T, Philips MR System Achieva, Eindhoven, the Netherlands). The dorsolateral part of the STN was selected as the target. In the morning of the surgery, a Leksell® frame (Elekta Inc., Stockholm, Sweden) was mounted on the head of the patient. Next, computed tomography (CT) was performed without contrast with a slice thickness of 0.625 mm (Aquillon® 16 CT scanner, Toshiba, Tokyo, Japan). The MR and CT images were then merged, and stereotactic coordinates were obtained using the Framelink 5 software (Medtronic, Minneapolis, USA). The surgery was performed under local anesthesia, starting on the side contralateral to the PD-dominant side in all patients. A combination of intraoperative microelectrode recording (MER) and macrostimulation was used intraoperatively in all patients. The test electrode was withdrawn and replaced with a permanent electrode (Model 3389; Medtronic Inc., Minneapolis, USA). The electrode was fixed on the cranium using a plastic cap (Stimloc®, Medtronic Inc). The same procedure was performed on the contralateral side. Postoperatively, all patients underwent MR imaging for the detection of complications and evaluation of electrode positions. Afterward, the pulse generator (Activa PC; Medtronic, Minneapolis, USA) was internalized.

Table I: Demographical Characteristics of the Patients

Patients	Gender	Age (year)	Education in years
1	Male	48	8
2	Male	70	4
3	Female	60	4
4	Female	64	0
5	Female	60	0
6	Male	68	4
7	Female	57	4
8	Female	56	4
9	Female	73	0
10	Female	64	0
11	Male	69	4
12	Male	58	4
13	Female	60	4
14	Male	62	16
15	Male	69	4
16	Male	51	4
17	Female	62	14
18	Male	73	8
19	Male	69	4
20	Male	59	4

Voice Analysis

Acoustic voice samples were recorded directly in Praat 6.0.26 using a MacBook Pro (2.6 GHz Intel Core i5) with a microphone positioned at an angle of 90° and at a distance of 5 cm that was maintained throughout the recording session in a silent room. The samples were digitized at 44.100 Hz (Praat Phonetics program<http://www.fon.hum.uva.nl/praat>). Upon instruction, the patients were supposed to sustain the vowels /a/, /i/, and /o/ as long as possible after taking a deep breath. Before the voices were recorded, two trials were performed for each sound. For acoustic analysis, a 3-s middle interval among the vowels was selected. The following voice parameters were analyzed: average fundamental frequency (F0), jitter (%), jitter relative average perturbation (RAP) (%), jitter period perturbation quotient (PPQ5) (%), jitter difference of differences of periods (DDP) (%), shimmer local (%), shimmer apq3 (%), shimmer apq11 (%), shimmer (%), mean noise-to-harmonic ratio (NHR), mean harmonic-to-noise ratio (HNR), and diadochokinetic assessment (DDK) rate (syll/s). For formant analysis, the first three formants (F1, F2, and F3) were analyzed by selecting a 20-ms segment of the vowels /a/, /i/, and /o/. F0 was calculated manually for each vowel using Praat (Version 6.1; Amsterdam; Netherlands) by the first author.

For diadochokinetic assessment, the patients were instructed to repeatedly say /pa/-/ta/-/ka/ consonant–vowel syllables in one deep breath. The syllables were counted for each patient.

Statistical Analysis

The Shapiro–Wilk's test was used for normality analysis of total results and results including the gender factor. Without considering the gender factor, the related-samples Friedman's two-way analysis of variance (ANOVA) was conducted for all acoustic parameters, including formants and DDK rate, for comparing groups. Statistical analysis was performed using the statistical package for the social sciences software, version 20.0 (IBM Corp., Armonk, NY, USA).To determine which group was statistically significant, pairwise comparisons were performed. The Dunn's pairwise post-hoc test was used for the correction. To analyze the gender factor, the related-samples Friedman's two-way ANOVA by ranks was used. Female and male data were presented as mean ± standard deviation.

RESULTS

This study prospectively recruited 20 patients (10 females and 10 males; age range, 48–73 years; mean age, 60.2 ± 6.9 years) diagnosed with PD (Table I). Each acoustic parameter of the vowels was compared among the preoperative med-on (Preop MedOn), postoperative "stimulation on" (stim-on) + med-on (Postop MedOn/StimON), and postoperative "stimulation off" (stim-off) + med-on (Postop MedOn/StimOff) groups. A significant difference was found in some parameters among the groups for some vowels. Then, we analyzed which groups are statistically different. A statistical significance was observed between the Preop MedOn and Postop MedOn/StimOn groups and between the Postop MedOn/StimOn and Postop MedOn/StimOff groups. No statistical significance was found between the Preop MedOn and Postop MedOn/StimOff groups. No statistical significance based on sex was found in any group. However, to show the difference among the Preop MedOn, Postop MedOn/StimOn, and Postop MedOn/StimOff conditions, data are presented as mean ± standard deviation according to gender.

Difference in Acoustic Parameters Between the Preop MedOn and Postop MedOn/StimOn Groups

A significant difference in the phonation of vowels /a/ and /o/ was observed between the above-mentioned groups. However, the difference was not significant for vowel /i/.

For vowel /a/, a statistically significant difference in all jitter parameters was observed. For vowel /o/, statistically significant differences were noted in jitter RAP, jitter PPQ, and jitter DDP parameters. The jitter values of the Postop MedOn/StimOn group decreased for vowels /a/ and /o/ ($p<0.05$). However, the differences in the shimmer values between the groups for the vowel /o/ were not significant; whereas those found in shimmer APQ 5, APQ 11, and the average absolute differences between the amplitudes of consecutive periods (shimmer DDA) for vowel /a/ were significant. Regarding HNR, a statistically significant difference was found only for vowel /a/, and the vowels /a/ and /o/ were found to be significant for NHR.

Formants (F0, F1, F2, and F3)

No significant differences in any formants were detected for vowels /a/ and /i/. For vowel /o/, a statistically significant difference in F3 was observed. Tables II–IV presents detailed information on the acoustic parameters.

Difference in the acoustic parameters between the Postop **MedOn/StimOn and Postop MedOn/StimOff groups**

Significant differences in some acoustic parameters were observed between both the groups for all vowels.

For vowel /a/, no statistically significant difference in the jitter values was observed (Table II); however, a statistically significant difference in all jitter parameters was observed for the vowels /o/ and /i/. Significant shimmer values were as follows: shimmer %, shimmer APQ5, and shimmer DDA for vowels /a/ and /i/. Only shimmer APQ3 showed a significant difference for vowel /i/. For vowel /o/, only shimmer APQ11 showed a significant difference (Table III). NHR values were significant for all vowels. For the HNR parameter, significance was observed for the vowels /a/ and /i/, whereas no significance was noted for vowel /o/. All parameters, except for HNR and NHR, increased in the Postop MedOn/StimOff group.

Formants

No statistically significant difference in F0 was observed for any vowels. F1 was significant for vowel /i/. F2 and F3 were significant for vowel /o/. No formants were significant for vowel /a/. In the Postop groups, F0 and F1 increased, whereas F2 and F3 decreased for vowel /a/.

When the acoustic parameters were compared between the Preop MedOn and Postop MedOn/StimOn groups, a

Table II: Comparison of the Groups for Vowel /a/

	Preop MedOn	Postop MedOn/ StimOn	Postop MedOn/ StimOff	Preop MedOn - Postop MedOn/ StimOn	Postop MedOn/ StimOn-Postop MedOn/StimOff
Acoustic Parameters		**Mean/SD**		**p**	**p**
	/a/	/a/	/a/	/a/	/a/
Jitt %	1.00 ± 1.28	0.34 ± 0.15	0.5 ± 0.39	**0.034***	ns
Jitt RAP	0.52 ± 0.63	0.19 ± 0.16	0.61 ± 0.75	**0.022***	ns
Jitt PPQ	0.61 ± 0.75	0.21 ± 0.15	0.28 ± 0.18	**0.002***	ns
Jitt DDP	1.5 ± 1.91	0.52 ± 0.24	0.0.66	**0.022***	ns
Shim%	9.55 ± 5.43	4.38 ± 1.82	8.5 ± 3.6	**0.003***	ns
ShimAPQ3	4.66 ± 3.06	2.12 ± 0.99	4.25 ± 2.5	ns	ns
ShimAPQ5	6.03 ± 3.79	2.67 ± 1.13	5.03 ± 2.33	ns	**0.013***
ShimAPQ11	8.52 ± 5.62	3.971.84	7.09 ± 1.54	ns	ns
Shim DDA	14.48 ± 8.79	6.49 ± 2.79	12.87 ± 7.69	**0.003***	**0.003***
NHR	0.15 ± 0.24	0.03 ± 0.04	0.05 ± 0.55	**0.002***	**0.002***
HNR	13.16 ± 6.17	19.67 ± 3.40	15.5 ± 3.42	**0.003***	**0.013***
F0	171.88 ± 42.74	173.59 ± 32.26	176.53 ± 32.84	ns	ns
F1	767.55 ± 158	725.52 ± 143.85	769.88 ± 136.33	ns	ns
F2	1317.63 ± 353.11	1348.49 ± 263.82	1276.35 ± 123.52	ns	ns
F3	2695.95 ± 420.45	2858.62 ± 354.30	2814.39 ± 210.35	ns	ns

:** *p<0.005,* ***ns: *not significant,* ***sd:*** *standart deviation.*

Table III: Comparison of the Groups for Vowel /o/

	Preop MedOn	Postop MedOn/ StimOn	Postop MedOn/ StimOff	Preop MedOn - Postop MedOn/ StimOn	Postop MedOn/ StimOn-Postop MedOn/StimOff
Acoustic Parameters		**Mean/SD**		**p**	**p**
	/o/	/o/	/o/	/o/	/o/
Jitt%	0.55 ± 0.5	0.28 ± 0.24	0.46 ± 0.29	ns	**0.027***
Jitt RAP	0.28 ± 0.29	0.13 ± 0.14	0.25 ± 0.17	**0.017***	**0.005***
Jitt PPQ	0.32 ± 0.34	0.17 ± 0.15	0.25 ± 0.16	**0.027***	**0.006***
Jitt DDP	0.87 ± 0.89	0.41 ± 0.43	0.79 ± 0.51	**0.027***	**0.001***
Shim%	6.61 ± 6.34	4.9 ± 4.25	4.98 ± 2.6	ns	ns
ShimAPQ3	3.26 ± 3.38	2.3 ± 2.07	2.51 ± 1.59	ns	ns
ShimAPQ5	4.28 ± 4.49	2.91 ± 2.62	3.04 ± 1.65	ns	ns
ShimAPQ11	5.82 ± 4.92	4.24 ± 3.31	3.93 ± 2.03	ns	**0.043***
Shim DDA	9.96 ± 10.02	6.49 ± 6.2	7.99 ± 4.61	ns	ns
NHR	0.05 ± 0.08	0.01 ± 0.004	0.02 ± 0.01	**0.022***	**0.048***
HNR	19.41 ± 6.82	23.61 ± 6.88	21.06 ± 4.32	ns	ns
F0	186.5 ± 4401	180.05 ± 40.28	232.04 ± 229.44	ns	ns
F1	582.37 ± 176.94	548.4 ± 153.7	544.47 ± 140.09	**0.022***	ns
F2	1270.99 ± 617.9	978.88 ± 204.58	969.28 ± 454.83	0.034*	0.022*
F3	2896.33 ± 360.4	2649.33 ± 309.12	2789.67 ± 700	ns	Ns

:** *p<0.005,* ***ns: *Not significant,* ***sd:*** *Standart deviation.*

significant decrease in the total values of the Postop MedOn/StimOn group was noted for vowels /a/ and /o/. However, the total values for vowel /i/ increased in the in the Postop MedOn/StimOn group compared with the Preop MedOn group (Table IV).

For the DDK measurement, a statistically significant difference was found in all groups. Table V presents the differences in DDK values according to groups.

Figure 1A shows the jitter and shimmer results for female (n=10) patients for vowels /a/, /o/, and /i/. For vowel /a/, a significant decrease was observed in all parameters during the Postop MedOn/StimOff condition, and shimmer DDA increased. An obvious decrease in all parameters for male (n= 10) patients during the Postop MedOn/StimOn condition was observed (Figure 1B). The possible effects of the stimulation were observed between the Postop MedOn/StimOn and Postop MedOn/StimOff conditions. Figures 2, 3, and 4 show the formant frequencies of female and male patients, NHR results according to gender, and HNR results, respectively.

DISCUSSION

The number of acoustic analysis studies on STN-DBS has increased in the past few years. However, the findings regarding parkinsonian voice and the effects of STN-DBS on voice differ across the studies. Both negative and positive effects have been reported. These studies vary in the factors used, including medication status, gender (29), disease duration, frequency modulation (15) methodology (28), and acoustic characteristics of voice (2), and speech (1,23). Another factor to be considered is that the patient characteristics contribute to the speech and voice of patients with PD (18). Subjective improvements in speech might be an influential factor that leads to a different outcome in some patients (21).

Table IV: Comparison of the Groups for Vowel /i/

	Preop MedOn	Postop MedOn/StimOn	Postop MedOn/StimOff	Postop MedOn/StimOn-Postop MedOn/StimOff
Acoustic Parameters		**Mean/Sd**		**p**
	/i/	**/i/**	**/i/**	
Jitt%	0.39 ± 0.19	0.46 ± 0.52	0.57 ± 0.24	**0.002***
Jitt RAP	0.21 ± 0.12	0.98 ± 3.3	0.31 ± 0.13	**0.002***
Jitt PPQ	0.22 ± 0.1	0.28 ± 0.27	0.33 ± 0.14	**0.004***
Jitt DDP	0.63 ± 0.37	0.74 ± 0.78	0.96 ± 0.40	**0.001***
Shim%	6.04 ± 4.81	3.77 ± 2.49	6.4 ± 1.82	**0.006***
ShimAPQ3	3.09 ± 2.51	1.64 ± 1.29	3.5 ± 1.12	ns
ShimAPQ5	3.63 ± 3.27	2.19 ± 1.63	3.85 ± 1.24	**0.005***
ShimAPQ11	4.72 ± 3.37	3.38 ± 2.62	4.78 ± 1.32	ns
Shim DDA	9.18 ± 7.32	5.09 ± 3.7	10.32 ± 3.23	**0.017***
NHR	0.06 ± 0.08	0.25 ± 1.06	0.03 ± 0.01	**0.017***
HNR	17.58 ± 7.19	22.01 ± 5.16	15.93 ± 1.88	**0.006***
F0	185.67 ± 41.8	176.4 ± 40	183.06 ± 24.37	ns
F1	451.38 ± 182.68	432.26 ± 193.81	459.55 ± 177.56	**0.022***
F2	2075.94 ± 446.44	2166.95 ± 422.62	2183.94 ± 357.3	ns
F3	2851.75 ± 246.64	3004.86 ± 288.64	3014.39 ± 303.08	ns

:** *p<0.005,* ***ns: *Not significant,* ***sd:*** *Standart deviation.*

Table V: Comparison of the Statistical Significance of Diadochokinetic (DDK) Assessment Measurement in all Groups

	Preop MedOn - Postop MedOn/StimOn	Postop MedOn/StimOn-Postop MedOn/StimOff	Preop MedOn - Postop MedOn/StimOff
DKK	**0.004***	**0.000***	**0.034***

***p<0.005.**

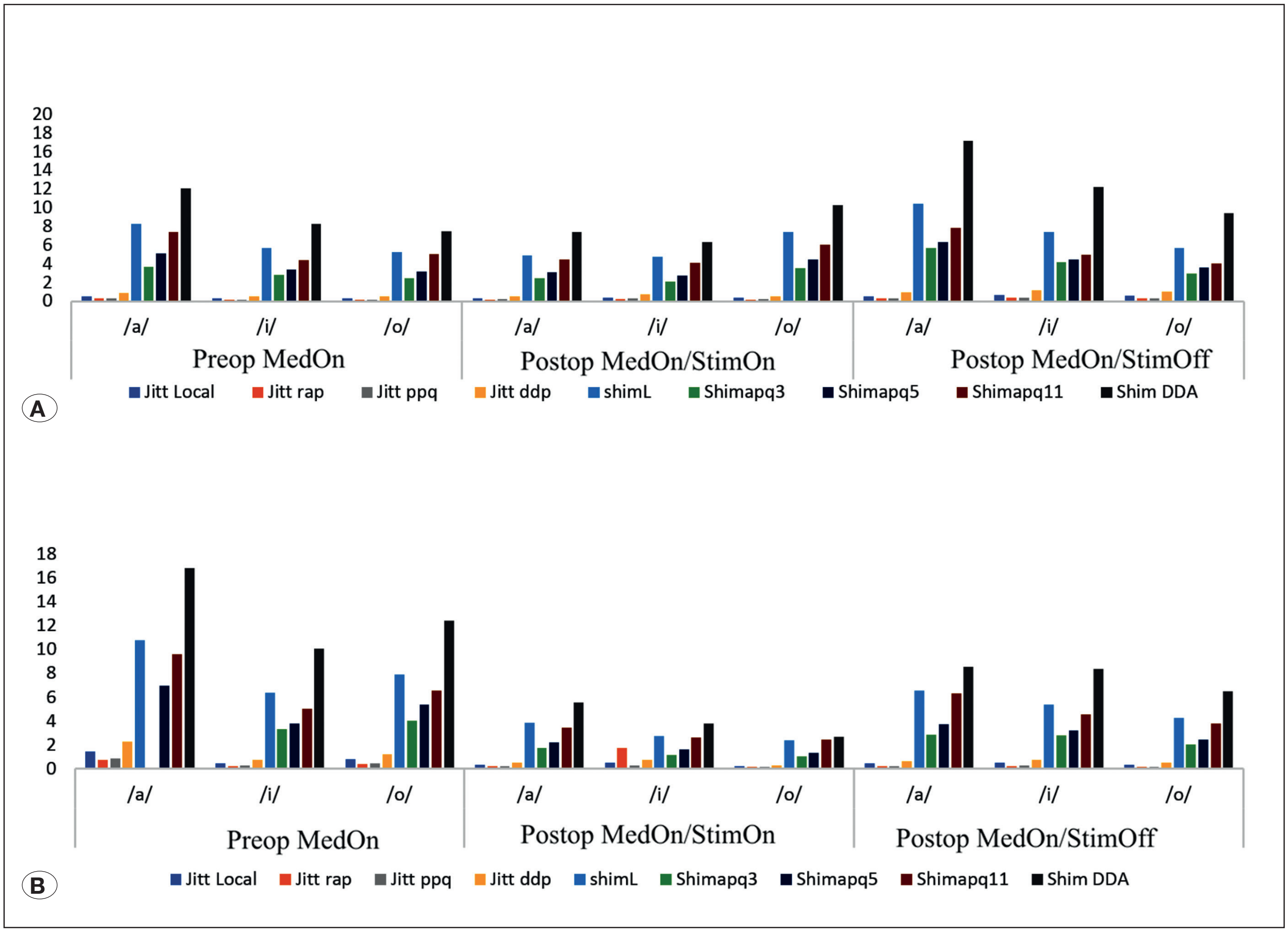

Figure 1: Jitter and shimmer results of **(A)** female and **(B)** male patients for vowels /a/, /o/ and /i/.

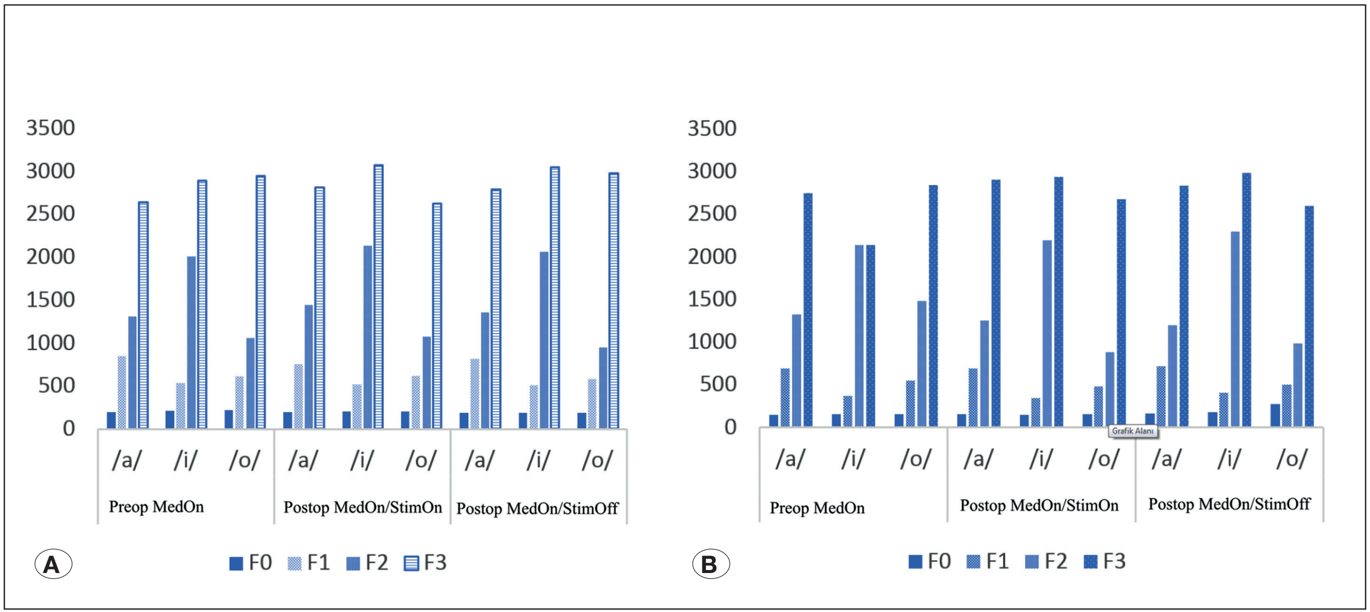

Figure 2: Formant frequencies of **(A)** female and **(B)** male patients.

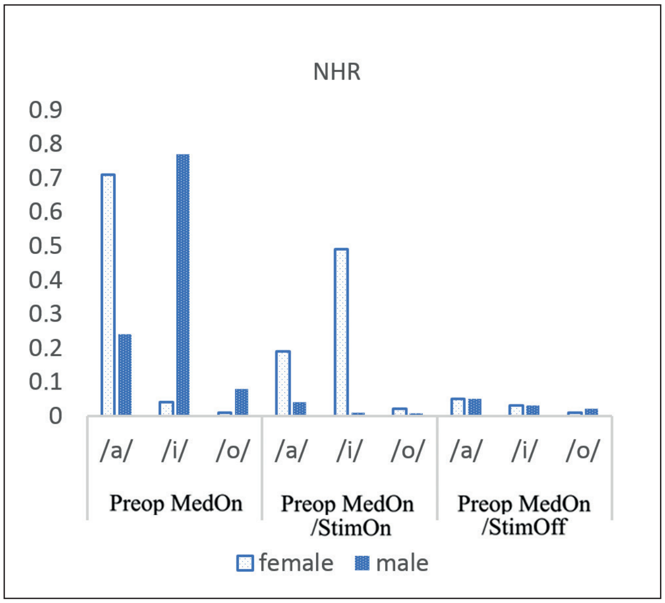

Figure 3: Noise-to-harmonic ratio (NHR) results of patients according to gender.

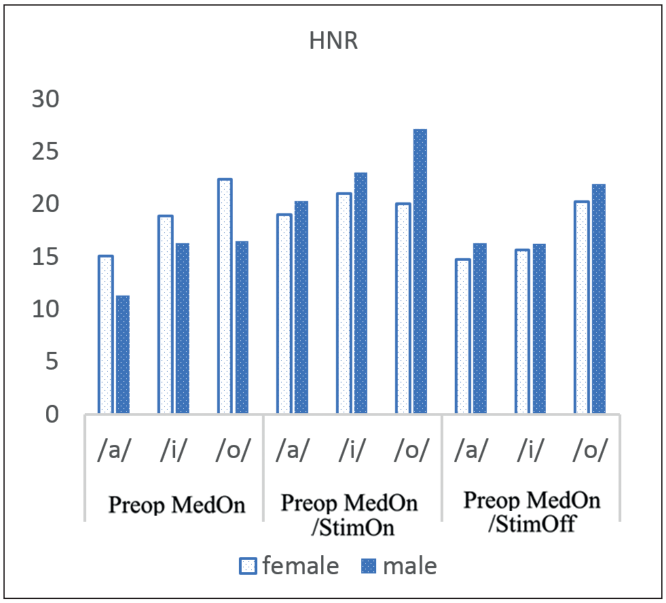

Figure 4: Harmonic-to-noise ratio (HNR) results of patients according to gender.

This study was conducted to determine whether bilateral STN-DBS influences acoustic parameters in Turkish patients with PD. Acoustic parameters provide basic information that explains the patients' voice characteristics at the time of recording. Thus, we could objectively explain the voices and their individual differences to the patients. According to the present study, acoustic analysis of the voices of patients with PD indicated that STN-DBS resulted in a decrease in the total results for the vowels /a/ and /o/ but an increase in the total results for vowel /i/. Mate et al. reported that jitter and shimmer decrease after STN-DBS, but only jitter significantly decreases in the "stim-on" condition (14). Skodda et al. found no significant differences in the acoustic parameters, but they reported higher values for loudness in the "stim off" condition (23). Tanaka stated that the acoustic parameters in patients (both males and females) who are receiving medical therapy are significantly better in the "stim-on" condition (25).

Patients in the present study showed significant differences in the acoustic parameters jitter %, jitter RAP, jitter PPQ, jitter DDP, shimmer %, shimmer DDA, NHR, and HNR in the /a/ phonation when the Preop MedOn and Postop MedOn/StimOn conditions were compared. The jitter and shimmer values of the patients decreased significantly consistent with the findings of a previous study (14). As a perturbation measurement, jitter indicates the extent of variation in the voice range. Shimmer is an amplitude perturbation measure that provides information on voice roughness. Another measure that represents hoarseness is HNR, which gives information about the amount of noise in a speech signal, primarily because of incomplete vocal fold closure (3). According to the jitter, shimmer, and HNR results of the patients in the present study, the "stim-on" condition has a positive effect on the harshness and rough quality of voice. Notably, an increase in the HNR and a decrease in the jitter and shimmer values were noted in all (Preop MedOn, Postop MedOn/StimOn, and Postop MedOn/StimOff) conditions. This is an adverse condition noted in the voices of patients with dysarthria. Dysarthria can be observed after neuromodulation. In our opinion, dysarthric voice quality, such as hoarse and harsh voice quality, reduces after stimulation. Jitter, shimmer, NHR, and HNR are objective variables to measure the hoarse or harsh quality of the voices of patients undergoing STN-DBS.

NHR is the ratio of inharmonic sound wave part to the harmonics part and provides information on the incomplete closure and incorrect oscillations of the vocal fold. Both NHR and HNR refer to hoarseness in the voice quality. NHR was significant in the vowels /a/ and /o/ in the comparisons between the Preop MedOn and Postop MedOn/StimOn conditions as well as in those between Postop MedOn/StimOn and Postop MedOn/StimOff conditions. Significant findings in these measurements indicate recovery in voice parameters, particularly in the Postop MedOn/StimOn condition. Different from those in vowel /a/, all jitter parameters were significant in the comparisons between the Postop MedOn/StimOn and Postop MedOn/StimOff conditions in vowel /o/. This might be explained by the acoustic characteristics of vowel /o/. Although significant results could be achieved according to gender, the mean ± SD values of NHR showed obvious differences between the Preop MedOn and Postop MedOn/StimOn conditions (Figure 3).

Vowel production is another important factor in the speech of patients with PD. Several studies have reported the effects of STN-DBS on vowel production and speech intelligibility (28,30), however, studies on formant frequency are limited in terms of STN-DBS. The findings of these some previous studies differ based on the status of stimulation (13), medication (16), or both (29). Formant frequencies change according to age, sex, and language spoken. Moreover, different formant frequency values for vowels may be reported for the same language because of the methodological differences across studies (7). In the present study, we investigated the vowels /i/ (high, front, and nonround), /a/ (low, back, and nonround), and /o/ (low, back, and round) (10). F1 refers to the height of the vowel and is related to the constriction of the vocal tract and capacity of the pharyngeal cavity. F2 refers to the backness of the vowel and is related to the length of the oral cavity; F3 relates to the back of the oral cavity (12). In this study, we discussed our findings with the formant frequency findings obtained by Kopkallı-Yavuz (11); however, the author did consider gender as a covariate. We found a statistical significance in only a few vowels. To summarize, the patients showed significant differences in F1 and F2 for /o/ phonation between the Preop MedOn and Postop MedOn/StimOn conditions. A significant difference in F2 for /o/ phonation was found between the Postop MedOn/StimOn and Postop MedOn/StimOff conditions. In addition, a significant difference in F1 was noted between the Postop MedOn/StimOn and Postop MedOn/StimOff conditions for /i/ phonation. Most significant differences were noted in vowel /o/. Differences between the formant frequencies of the vowels of the patients in the present study were similar to the average formant frequencies of Turkish healthy subjects reported in the study by Kopkallı-Yavuz (11).

Patients with motor-speech disorders usually do not have a good DDK score (9). The DDK rate reveals how rapidly a patient can change an articulatory position to another as this rate refers to the maximum production of rapid syllable repetition (26). In this study, the DDK rates improved in all groups. Thus, STN-DBS might have a positive acute effect on the DDK rate.

In this study, to minimize the heterogeneous profile of the patients with PD, second voice recordings were collected from all patients a month after the surgery. The deterioration in voice and motor control of speech may increase with time (22). Our results revealed the acute effects of DBS on voice.

The overall assessment of voice and motor control of speech may be more informative in the investigation of STN-DBS effects on voice. In this study, we investigated both acoustic parameters, including formants, and DDK measurements to evaluate the performance of the patients in different perspectives.

Our data revealed no significant findings according to patient sex. Xie et al. found similar results when considering the sex factor (29). Sarac et al. indicated that the acoustic voice quality in females deteriorated after STN-DBS, but they did not observe any deterioration in audioperception (20). In this study, when mean values were examined, no discriminating differences in the formants were observed between the groups according to gender. The number of patients might have contributed to the results. The articulatory abilities of the patients in this study did not deteriorate, and most of them had an intelligible speech. Decrease in the physiological symptoms of patients might have had a positive effect on their voices. Adding perceptual voice evaluations to acoustic analyses might have provided information on the patients' perception of their voice after STN-DBS.

CONCLUSION

STN-DBS surgery has a positive acute effect on voice. In further studies, it will be beneficial to work with larger populations, particularly stratified based on gender. In addition, regular, short-duration evaluation of patient voices with long-term follow-ups may help determine the effects of STN-DBS more clearly. Studies on formant frequency analysis in STN-DBS may be expanded with both articulation and intelligibility tests to enable us to combine patient abilities in several perspectives and obtain more precise results.

AUTHORSHIP CONTRIBUTION

Study conception and design: OCY, SO, OK

Data collection: OCY, SO

Analysis and interpretation of results: OCY, OK, EK

Draft manuscript preparation: OCY, SO

Critical revision of the article: OCY, SO, OK, EK

Other (study supervision, fundings, materials, etc...): OK, EK

All authors (OCY, SO, OK, EK) reviewed the results and approved the final version of the manuscript.

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