Original Article

The effects of rapid maxillary expansion on voice function

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ABSTRACT

Objective: To evaluate the effects of rapid maxillary expansion (RME) on vocal function in patients with bilateral maxillary crossbite.

Materials and Methods: We designed our research as a prospective, controlled, clinical study. The treatment group and the control group each had 20 subjects for a total of 40 subjects. Acoustic voice samples were recorded from all patients at T_1 and T_2 by the Multi-Dimensional Voice Program (MDVP Model 5105) for acoustic analysis in Computerized Speech Lab (CSL).

Results: No statistically significant differences were found between the treatment and control groups in the means of any parameters.

Conclusions: RME does not change vocal quality or resonance, so it can be safely used with patients. (*Angle Orthod.* 2017;87:49–55)

KEY WORDS: Rapid maxillary expansion**;** Voice function

INTRODUCTION

Rapid maxillary expansion (RME) has been used for over 150 years as a part of orthodontic treatment in patients with a narrow maxilla.[1] Researchers have generally observed unilateral or bilateral crossbites, crowded teeth, constricted and tapered maxillary arch, mouth breathing, low tongue posture (with greater intraoral airway volume), and nasal obstruction in patients having maxillary deficiency.[2] Chronic mouth breathing, whether or not it is caused by nasal obstruction, leads to an undesirable development of muscle function, as well as soft and hard tissue morphology, including facial bones and dental arches.[3] Recent studies have reported that RME therapy causes a straightening of the nasal septum, lowering of the palatal vault, and an increase in nasal width and volume, all of which facilitate nasal respiration in mouth breathers.[4–6] Gray[7] reported that 80% of patients converted from mouth breathing to nose breathing after RME therapy. Expansion of the upper airway may affect voice quality as a result of skeletal changes.[8]

Formation of the voice is a complex physiological process involving interaction among the respiratory, laryngeal, and resonance subsystems. Surgery of the oral, nasal, or pharyngeal areas can affect vocal quality.[9] Nasal obstruction is one of the etiological factors in voice disorders.[10] Vowel formant frequencies (F_1, F_2) are affected by the shape of the vocal tract and are dependent upon the tongue position relative to the hard palate and pharynx. F_1 values vary mostly with changes in tongue height, while F_2 varies mostly with changes in tongue advancement.[11] In 2005, Moura et al. found an apparent increase in F_1 frequency among the RME group in their study of Down syndrome patients. According to the authors, this was explained by expansion of the airways caused by RME, enlargement of the vocal tract, and provision of enough space for the tongue.[8]

Computerized Speech Lab (CSL; Kay Elemetrics, Lincoln Park, NJ) was used for acoustic voice analysis; it includes the Multi-Dimensional Voice Program (MDVP; Kay Elemetrics) and the Real-Time Spectrogram Program.[9] The MDVP, which is the gold standard of software tools, calculates more than 22 parameters for a single vocalization.[12] Computer-assisted voice analysis programs provide objective, reproducible, and noninvasive acoustic measurements, all of which represent an important diagnostic advancement.[13] The MDVP compares acoustic variables both graphically and numerically with a specially built normative

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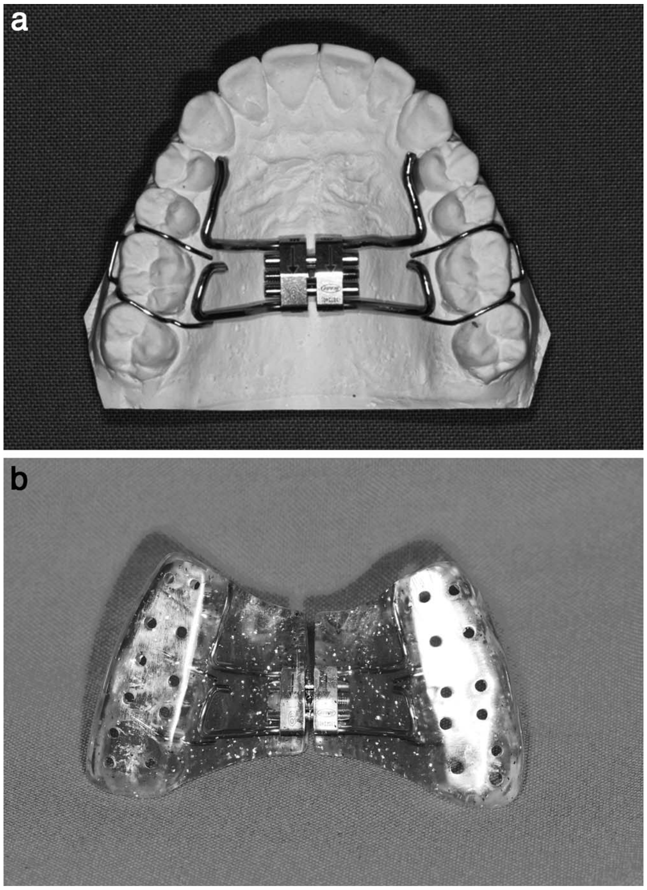

Figure 1. (a, b) Design of modified McNamara RME appliance.

database. Thus, pathological vocal abnormalities can be differentiated from healthy voices.[12,13]

To the best of our knowledge, adequate studies have not been conducted on the effects of RME on nonsyndromic patients' vocal quality. We designed our study for further elaboration on the relation between dentoskeletal discrepancy and voice quality. The hypothesis of our study was that RME therapy affects voice quality because it results in an altered, anterior placement of the tongue.[14]

MATERIALS AND METHODS

We designed our research as a prospective, controlled, clinical study. The treatment group included 20 subjects (14 females and 6 males, mean age: 14.16 ± 1.71; range: 12–17), as did the control group (13 females, 7 males; mean age: 14.4 ± 1.42; range: 12–17) totaling 40 subjects. All patients had permanent dentition. Inclusion criteria for the treatment group were as follows: (1) presence of transverse maxillary deficiency and need of RME therapy because of bilateral crossbite and (2) Class I occlusal relationship. For the control group, the criteria included (1) no bilateral, unilateral crossbite, or buccal nonocclusion, (2) a regular transverse maxillary relationship, and (3) a Class I occlusal relationship. Exclusion criteria were as follows for both groups: (1) history of orthodontic treatment, (2) history of nasal or pharyngeal surgery, (3) presence of systemic disease, and (4) smoking.

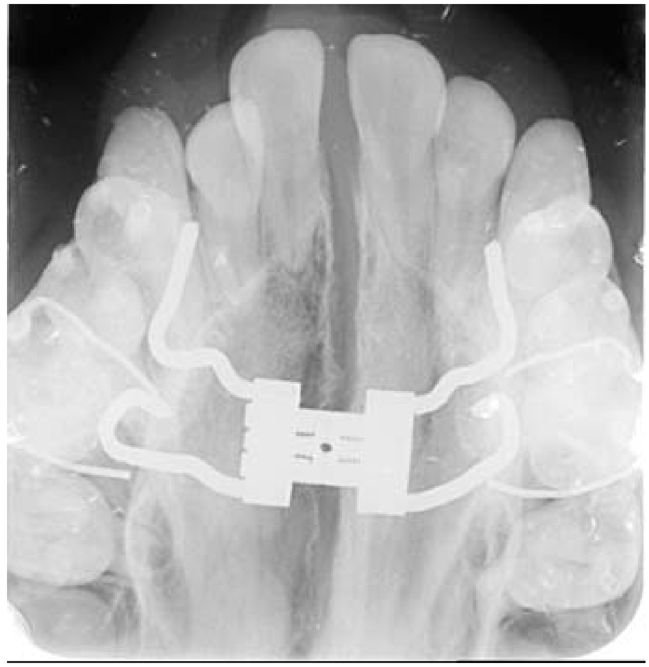

Figure 2. Occlusal radiograph taken 1 week after application of RME.

Approval for the study was obtained from the Regional Ethics Committee at the Medicine Faculty of Selcuk University (No. 2013/60). Written informed consent was obtained from all patients after explaining details of the study.

Acoustic voice samples were recorded from all patients at T_1 and T_2. T_1 represented inititation for the control group and before RME cementation for the treatment group. T_2 represented 4 months after the first control group measurement and at the end of the retention period (appliance removal) for the treatment group. Our main goal was to evaluate the effects of maxillary expansion and nasal changes on voice function at the end of expansion.

We used the modified McNamara[15] RME appliance in the treatment group by adding acrylic to the palate area. To increase stability, Adams clasps were adapted to the first molars (Figure 1a,b).

Following cementation of the appliance, the clinician made the first turn of the hyrax screw (G&H Wire Co, Franklin, Ind). Then the patients' parents were told how to turn the screw and how to activate the expansion appliance with a swivel key. The appliance was activated with a quarter turn ($2 \times \frac{1}{4}$ turn $= 0.5$ mm) twice daily during the first week to overcome the resistance of the midpalatal suture; activation was reduced to a quarter turn once per day after the suture had opened radiographically (Figure

Figure 3. Patient's photo during phonation of /a/.

2), then continued until 2–3 mm overexpansion (overcorrection) was obtained (average time: 4–6 weeks). After the expansion period, a stainless steel ligature wire was tied around the Hyrax screw. The same appliance was used as a retainer for 3 months.

In the present study, laryngeal voice was evaluated by objective acoustic analysis. The amount of velopharyngeal closure varied during the pronunciation of a letter having different sounds. During the phonation of the /a/ vowel, the tongue was lowered, and the closure or constriction of the vocal tract did not occur the same as did other vocals. In addition, the /a/ vowel serves as the phonological core of many syllables.[9,16,17] Thus, we have examined the parameters of the /a/ vocal in evaluating the voice.

All voice samples were recorded in a quiet room using a head-mounted microphone (Shure SM 58; Shure Inc, Niles, Ill) at an approximately 5–10-cm microphone-mouth distance in an off-axis position (45° to 90° from the mouth axis)[18] (Figure 3). Before recording, patients were allowed to rest for at least 15 minutes. After a deep inspiration, the subjects were asked to phonate the vowel /a/ three times for 5 seconds in the standing position. The voice samples were recorded with the MDVP Model 5105 for acoustic analysis in CSL. The highest-quality data from three recorded samples were chosen, and voice samples between the first and fourth seconds were analyzed with MDVP software to reduce variability. Mean $F_{0,}$ jitter and shimmer percentage, relative average perturbation (RAP), amplitude perturbation quotient (APQ), and noise-to-harmonic ratio (NHR) acoustic parameters were then examined. Definitions:

- Fundamental frequency (F_0; Hz): number of vibrations of the vocal fold per second[19]
- Jitter percentage: short-term (cycle-to-cycle) variation in the fundamental frequency of a signal[18,20]
- Shimmer percentage: short-term (cycle-to-cycle) variation of voice amplitude between adjacent cycles of vocal fold vibrations[21]
- RAP (%): average absolute difference between a period and the average of that period and its two closest neighboring periods (with a smoothing factor of three periods for jitter), divided by the average period[18]
- APQ (%): smoothing factor for shimmer
- NHR (dB): average ratio of the inharmonic energy (noise) to the harmonic spectral energy[21]

For spectrographic analysis, the subjects, after a deep inspiration, were asked to phonate the vowel /a/ three times for 5 seconds. We recorded the voice samples with Real-Time Spectrogram Model 5129 software in CSL. The highest quality data from three recorded samples were chosen; voice samples between the first and fourth seconds were then analyzed with MDVP software to reduce variability. The mean values of F_1, F_2, F_3, and F_4 formants were then examined.

Statistical Analysis

We used the Kolmogorov-Smirnov test to determine that all parameters were normally distributed. Comparisons of the control and treatment parameters measured before and after T_1 and T_2 were performed using the paired-samples *t*-test. The independent samples *t*-test was used to compare the two independent groups. Descriptive statistics (mean ± standard deviation) were calculated in each group for all parameters. The interval plot (95% confidence interval for mean) was used for the graphics. The data were analyzed using the Statistical Package for Social Sciences (version 13.0, SPSS Inc, Chicago, Ill). The results were considered statistically significant if the *P* values were less than .05.

Table 1. Demographic Data of Both Groups

	Control Group (n = 20)		Treatment Group (n = 20)	
Age Groups	Male (n = 7)	Female (n = 13)	Male (n = 6)	Female (n = 14)
Mean ± SD[a]	14.72 ± 1.57	13.85 ± 1.57	14.05 ± 1.04	14.57 ± 1.56
Median	14.70	14.70	14.10	14.65
Interval	12.20–17	11–16.40	12.80–15.30	12.40–17

[a] SD indicates standard deviation.

Table 2. Comparison of T_1 and T_2 Values for the Treatment Group

	Treatment Group		
	T_1 (n = 20)	T_2 (n = 20)	*P*
F0	244.951 ± 54.510	243.822 ± 55.920	.644
F_1	882.535 ± 129.670	870.596 ± 140.307	.676
F_2	1528.242 ± 173.666	1468.579 ± 186.434	.216
F_3	3150 ± 310.235	3192.328 ± 254.457	.573
F_4	4068.766 ± 198.989	4095.218 ± 236.908	.695
Shimmer %	3.271 ± 1.416	2.862 ± 0.663	.252
Jitter %	0.867 ± 0.532	0.689 ± 0.326	.213
RAP	0.545 ± 0.350	0.407 ± 0.208	.135
APQ	2.256 ± 0.821	2.228 ± 0.808	.911
NHR	0.112 ± 0.014	0.109 ± 0.018	.489

Table 3. Comparison of T_1 and T_2 Values for the Control Group

	Control Group		
	T_1 (n = 20)	T_2 (n = 20)	*P*
F_0	240.888 ± 63.376	235.605 ± 60.291	.322
F_1	990.036 ± 715.545	846.202 ± 135.894	.383
F_2	1676.295 ± 783.954	1594.707 ± 336.832	.608
F_3	3177.394 ± 543.679	3215.834 ± 309.278	.713
F_4	4117.910 ± 331.138	4177.939 ± 306.718	.511
Shimmer %	3.499 ± 1.229	3.217 ± 1.348	.459
Jitter %	0.997 ± 0.668	1.035 ± 0.499	.818
RAP	0.596 ± 0.408	0.623 ± 0.308	.791
APQ	2.367 ± 0.891	2.318 ± 0.839	.837
NHR	0.114 ± 0.193	0.119 ± 0.023	.301

RESULTS

A power analysis was established by the G*Power version 3.1.2 software (Franz Faul, Universität Kiel, Kiel, Germany) based on a 1:1 ratio between the groups, which found that a total sample size of 40 patients (20 patients in each group) would give more than 80% power (actual power = 0.8123745, two groups, two repeated measurements) to detect significant differences with 0.40 effect size and at a .05 significance level.

Table 1 presents the mean values and standard deviations (SDs) of the sex and age of each group. There were no significant differences for age or sex factors between the treatment and control groups. The means ± SDs of F_0, F_1, F_2, F_3, and F_4; jitter and shimmer percentages, RAPs; APQs; NHRs(at T_1 and T_2), and results of intragroup comparison for the treatment and control group are presented in Tables 2 and 3. We found no significant differences between the treatment and control groups' means for any parameters. Figures 4 and 5 demonstrate the mean values of each parameter for both groups.

Comparisons between the two groups' values for mean acoustic measurements at T_1 were not statistically significant; Table 4 presents the descriptive statistics and the intergroup comparisons of all parameters at T_1. Table 5 presents intergroup comparisons of the difference (T_2–T_1) for all parameters. The differences were not statistically significant.

DISCUSSION

Voice and speech are complex physiological phenomena that result from interactions of the respiratory laryngeal and resonator systems.[22] Objective acoustic analysis is used for increasing sensitivity in diagnosing voice disorder; the method records both short- and

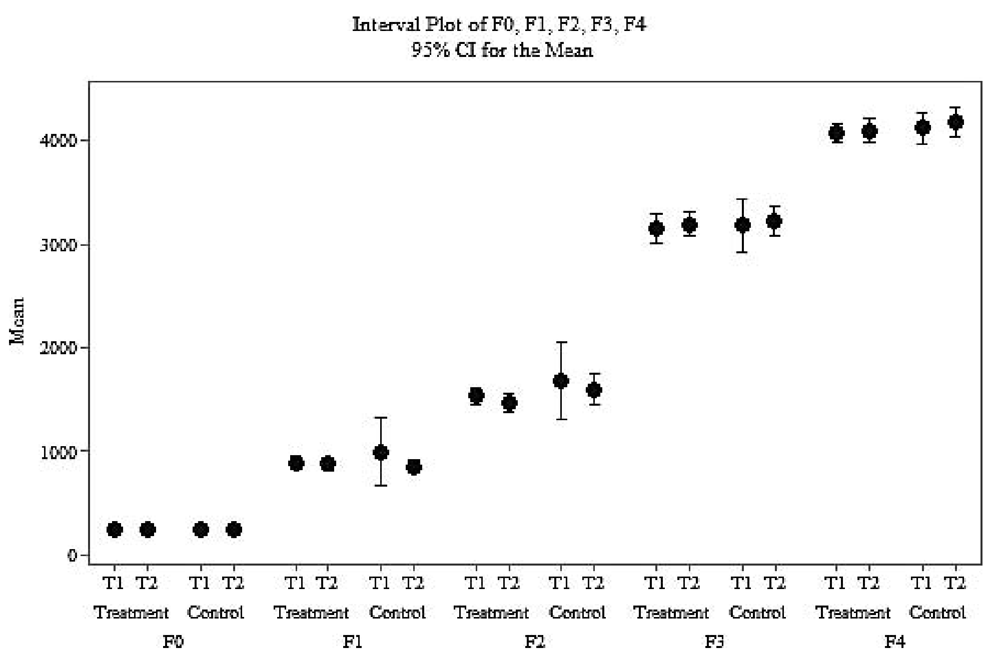

Figure 4. Interval plot graphic of F_1, F_2, F_3, and F_4 frequencies.

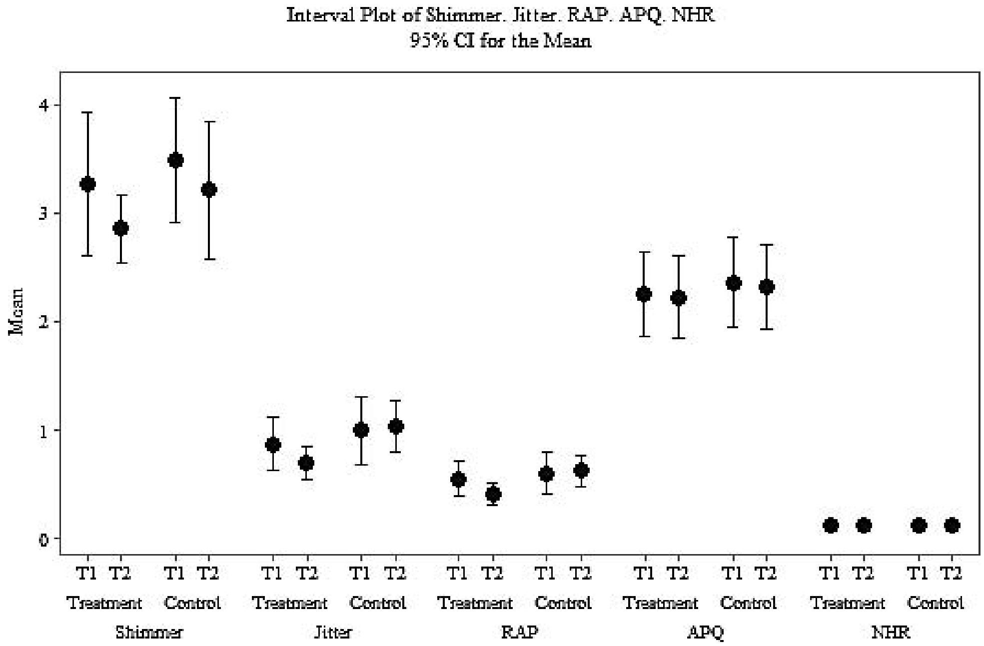

Figure 5. Interval plot graphic for shimmer and jitter percentages and APQ, NHR, and RAP parameters.

long-term treatment efficacy and allows for providing feedback to patients. Various software programs for performing acoustic analysis are available, with the CSL system being the most commonly used MDVP software. MDVP indicates objective acoustic norms and whether voice pathology exists.[18,22]

In the present study, after appliance removal, the RME group showed a decrease in both F_1 and F_2 frequencies and an increase in F_3 frequency, but these results were not statistically significant. Macari et al.[23] found a significant lowering of the first and second formants for the vowel /a/, but their study had a small sample size. In addition, they did not have a control group, explaining why our results may have been different.

We created the control group from individuals without crossbite because it was not ethical to make patients with crossbite wait for 4 months without treatment.

Our retention procedure was to continue the deactivated appliance for 3 months,[24] so we recorded voice samples after removing the appliance. In this study, voice records were not taken while the appliance was in the patients' mouth because our main purpose was not to investigate the effects of the RME appliance. Oral appliances can cause differences in speech production, usually affecting tongue posture and palatal volume. In their questionnaire study, De Filippe et al.[25] reported a negative influence of RME on speech. Stevens et al.[26] evaluated the effect of RME on speech articulation. After the RME appliance was installed, speech acceptability deteriorated in all individuals.

Kayıkcı et al.[17] used Hawley retainers and found statistically significant speech disturbances in consonants [ş] and [z]. In addition, the authors found that the F_1 frequency of the vowel /i/ increased, whereas F_2 and F_3 decreased. Sarı et al.[11] investigated the effect of surgical RME on vowel production. The F_2 frequency of the vowels /i/ and [œ] showed a decrease because the vowels were affected by the size of the anterior oral cavity.

In addition, no adequate study depicting the effects of RME on voice functions in nonsyndromic patients is available in the literature. In a controlled clinical trial performed by Moura et al.,[8] RME was applied on 12 children with Down syndrome between the ages of 4 and 12. To evaluate the effect of tongue positioning at different heights on voice functions and to investigate the effect of the area occupied by the tongue on the horizontal axis, they compared the voice records of the /a/, /i/, and /u/ vowels with those of the /i/ and /u/ vowels. They found no statistically significant differences between the two groups. Researchers reported maxillary expansion by separating the palatine bones

Table 4. Intergroup Comparison of All Parameters at T_1

	T_1		
	Control Group ($n = 20$)	Treatment Group ($n = 20$)	*P*
F_0	240.888 ± 63.376	244.951 ± 54.510	.829
F_1	990.036 ± 715.545	882.535 ± 129.670	.513
F_2	1676.295 ± 783.954	1528.242 ± 173.660	.415
F_3	3177.394 ± 543.679	3150 ± 310.235	.846
F_4	4117.910 ± 331.138	4068.766 ± 198.989	.573
Shimmer %	3.498 ± 1.228	3.271 ± 1.416	.590
Jitter %	0.997 ± 0.668	0.867 ± 0.532	.503
RAP	0.596 ± 0.408	0.545 ± 0.350	.673
APQ	2.367 ± 0.891	2.256 ± 0.821	.686
NHR	0.114 ± 0.019	0.112 ± 0.014	.648

Table 5. Intergroup Comparison of the Difference (T_2–T_1) for All Parameters

	Control Group (n = 20)	Treatment Group (n = 20)	Test	*P*
F_0	−5.5283 ± 23.212	−1.128 ± 10.737	−0.726	.474
F_1	−143.833 ± 719.763	−11.939 ± 125.870	−0.807	.425
F_2	−81.587 ± 700.431	−59.663 ± 208.576	−0.134	.894
F_3	38.440 ± 461.188	42.328 ± 329.965	−0.031	.976
F_4	60.029 ± 401.179	26.452 ± 297.036	0.301	.765
Shimmer	−0.282 ± 1.667	−0.408 ± 1.545	0.248	.805
Jitter	0.038 ± 0.725	−0.179 ± 0.622	1016	.316
RAP	0.027 ± 0.448	−0.138 ± 0.395	1233	.225
APQ	−0.048 ± 1.038	−0.028 ± 1.115	−0.059	.953
NHR	0.005 ± 0.191	−0.003 ± 0.187	1254	.217

and movement of the outer nasal wall through the lateral position. Thus, individuals can position their tongues more easily in the oral cavity so that the F_1 frequency increases in the treatment group.

Liberman[27] reported increased jitter percentages in pathological voices and emphasized the sensitivity of discrimination compared with normal and pathological voices. The jitter and shimmer values were associated with laryngeal airway resistance and incomplete velopharyngeal closure.[28] According to the results of the present study, the RME procedure caused no significant changes in the measurements of F_0, jitter or shimmer percentages, NHR, APQ, or RAP.

These results indicate that RME is a safe procedure that can be applied even in professional voice users. More studies are required due to the lack of data in the literature about this topic.

CONCLUSIONS

Bearing in mind this study's limitations:

- We detected no significant changes in F_1, F_2, F_3, or F_4 values in spectrographic analysis performed after RME.
- We detected no significant changes in the vocal parameters of F_0, shimmer and jitter percentages, APQ, RAP, or NHR after RME.
- Because RME does not change vocal quality or resonance, it is safe to apply on patients.

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