# EFFECTIVENESS OF VOCAL FOLD AUGMENTATION ON VOICE QUALITY OF PATIENTS WITH UNILATERAL VOCAL FOLD PARALYSIS

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## Abstract

Dysphonia is a frequent consequence of unilateral vocal fold paralysis (paresis), characterised by breathy voice quality, vocal fatigue, and short maximum phonation times. Injection laryngoplasty augmentation of the paretic vocal fold is a surgical procedure intended to improve glottal fold closure and alleviate symptoms of dysphonia. This article will present the preoperative and postoperative laryngological examination and voice assessment of patients undergoing vocal fold augmentation. The aim of the study is to evaluate changes in various areas of voice assessment (auditory-perceptual, acoustic, aerodynamic, and subjective) after vocal fold augmentation. The research sample consists of 30 individuals (15 female, 15 male) with unilateral vocal fold paralysis. Of all four evaluated areas, statistically significant improvements ($p<0.05$) after augmentation were recorded in nine parameters (G, B, jitter, shimmer, GNE, minimum frequency, maximum phonation times /a:/ and /z:/, and VHI-30). Based on our results, injection laryngoplasty leads to a significant short-term improvement in the voice quality of patients with unilateral vocal fold paralysis. The selected voice parameters are shown to be relevant and sensitive parameters for assessing the effectiveness of phonosurgical treatment. Their inclusion in a standardised protocol for objective assessment of patients with vocal fold paralysis is recommended.

## Keywords

unilateral vocal fold paralysis, vocal fold augmentation, voice assessment, laryngological assessment, dysphonia

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https://doi.org/10.36833/lkl.2026.003 Accepted for review: 14 September 2025 Accepted for publication: 4 March 2026 

## Introduction

Unilateral paralysis of the vocal folds arises on the basis of loss of innervation in one or more branches of the recurrent laryngeal nerve (Walton, 2016). The etiological factors of unilateral vocal fold paralysis include iatrogenic etiology, traumatic injury, neurological or oncological disease, intubation, viral infection, or idiopathic etiology (Spataro, 2014). It is manifested by the immobility of one vocal fold, which causes impaired adduction of the vocal folds and incomplete vocal fold closure (coaptation). Unilateral vocal fold paralysis frequently results in dysphonia, more rarely dysphagia (Walton, 2016). The estimated incidence of unilateral vocal fold paralysis is 5 cases per 100,000 inhabitants per year (Nouraei, 2015).

Dysphonia in unilateral vocal fold paralysis is characterized mainly by breathy and weak voice quality, reduced frequency and intensity range, voice fatigue and shortened phonation times. Diplophonia or compensatory hyperfunction of the supraglottis may be present, which can result in the development of vestibular voice. The severity of symptoms depends on the magnitude of the glottic insufficiency and, possibly, on the type of compensatory voice production developed (El-Banna and Yousef, 2014).

The purpose of intervention in unilateral vocal fold paralysis is to improve the glottic closure. Management options include non-interventional observation, voice therapy, and microlaryngosurgical approach. Voice therapy can be aimed at strengthening the healthy vocal fold with the intention of improving the glottic closure, improving respiratory support during phonation with respiratory exercises, compensating for glottic insufficiency with postural changes, as well as eliminating unhealthy vocal behaviour through vocal hygiene (Walton, 2016). The principle of microlaryngosurgical intervention can be augmentation, medialization or reinnervation of the paretic vocal fold. In injection laryngoplasty, the paraglottic space of the paretic vocal fold is filled in order to increase its volume (Siu, 2016). Medial thyroplasty is a permanent procedure in which the paretic vocal fold is shifted towards the midline with implanted material (Misono and Merati, 2012). Reinnervation of the paretic vocal fold takes advantage of the presence of other functional nerves in the anatomical vicinity of the *nervus laryngeus recurrens* in order to improve the tone and/or mobility of the paretic vocal fold (Misono and Merati, 2012; Siu, 2016).

Improving glottic closure leads to improved voice quality. Objective assessment of the effectiveness of microlaryngeal surgery requires a standardized protocol of ENT examination and voice assessment (Dejonckere et al., 2025), which aims to document the preoperative and postoperative quality of the voice and allows comparison. The aim of the current study is to evaluate changes in various parameters of voice analysis within preoperative and postoperative assessments in patients with unilateral vocal fold paralysis undergoing vocal fold augmentation by injection laryngoplasty.

### *Research methodology*

This prospective observational study was conducted at the Department of Otorhinolaryngology and Head and Neck Surgery of the Faculty of Medicine of Comenius University and University Hospital Bratislava from October 2023 to August 2025. The study consecutively included all patients undergoing vocal fold augmentation hospitalized at our department. The study was approved by the UNB Ethics Committee on 3 March 2025.

### *Study participants*

The study comprised 30 participants, 15 female and 15 male. Participants had to meet the following inclusion criteria:

- unilateral vocal fold paralysis,
- undergoing of unilateral injection laryngoplasty,
- age over 18 years.

Participants were excluded from the study if they did not complete the entire study protocol, if they did not undergo injection augmentation, or if they were diagnosed with another vocal fold pathology at the time of the examination.

The average age of the study participants was 58.5 years, with the youngest participant being 36 and the oldest participant 89 years old. In terms of etiological factors of unilateral vocal fold paralysis, 43.3% were iatrogenic (13 research participants), 40% were idiopathic (12 research participants), 13.3% of paralysis cases were caused by oncological disease (4 research participants) and 3.3% of cases resulted from sudden stroke (1 research participant).

The injected substance in all study participants was *calcium hydroxylapatite* (RenúVoice) and augmentation was performed from a transthyroid approach. The amount of injected material ranged from 0.2 mL to 1.3 mL, with an average amount of 0.8 mL.

All study participants were given the same voice analysis protocol. Participants with aphonia before injection augmentation were not able to provide certain parameters of acoustic (e.g. frequency range) and aerodynamic (e.g. maximum phonation times of voiced sounds) analysis. This led to a relatively large number of missing data in the preoperative assessment.

### *ENT examination and voice examination protocols*

Preoperative and postoperative assessment was performed with all study participants through the "ENT Examination Protocol" and the "Voice Examination Protocol" at two points in time. The preoperative examination was performed on the day of the augmentation procedure, while the postoperative assessment was performed at least two weeks after the procedure. The timing of the postoperative assessment is based on the recommendations of the Korean Society of Laryngology, Phoniatrics and Logopedics Guideline Task Force (2020) and aims to assess changes in the voice and complications after the procedure (rapid absorption, surface location, or migration of the injected material) that might require repeated injection. Acute post-injection changes such as hematoma, infection, or edema in most cases resolve within one week of the procedure, so they are not expected to have a significant effect on the quality of the patient's voice at the time of the postoperative check-up.

When compiling the "ENT Examination Protocol" and the "Voice Examination Protocol", we followed the Guidelines for the Management of Unilateral Vocal Fold Paralysis by the Korean Society of Laryngology, Phoniatrics and Logopedics Task Force (2020), the International Consensus (ICON) on Basic Voice Evaluation in Unilateral Vocal fold Paralysis (Mattei et al., 2018), the Basic Protocol for Functional Voice Assessment of the European ENT (Dejonckere et al., 2001) and the Consensus for Voice Quality Assessment in Clinical Practice: Guidelines of the European Laryngological Society and Union of the European Phoniatricians (Lechien, 2023).

The laryngological examination protocol includes anamnestic data about the patient: the etiology of unilateral vocal fold paralysis as well as any voice therapy underwent before the procedure. It also provides information about the anatomical and physiological conditions of the patient's vocal folds, as obtained during

a videoendoscopic examination carried out by an otorhinolaryngologist in cooperation with a speech therapist. The type of vocal fold closure is indicated, for which we distinguish: complete closure, anterior insufficiency, posterior insufficiency, hourglass-shaped closure, irregular closure, spindle-shaped insufficiency or incomplete closure (Eysholdt, 2019). The horizontal position of the vocal folds during respiration and phonation is recorded, where we determine the medial, paramedial, intermediate or lateral position (Olthoff, 2019). The protocol further accounts for vertical plane asymmetry, specifying whether the vocal folds are coplanar or out-of-plane due to the inferior displacement of either the left or right fold. Last but not least, the protocol collects data on the surgical procedure, recording the injection side, the type of anaesthesia, the volume of the injected substance, the number of injections required to perform the procedure, the approach chosen (trans-oral, trans-cricothyroid, trans-thyrohyoid, trans-thyroid), and injection complications.

The voice examination is carried out by an experienced speech therapist. Voice samples are recorded using a calibrated lingWAVES SPL meter II microphone. A mobile phone or recorder can be used for voice recording if a calibrated microphone is unavailable. The microphone is placed at a fixed distance of 30 cm from the mouth of the person being examined. Voice recording takes place in a quiet room. The voice examination includes the recording and analysis of aerodynamic, acoustic, auditory-perceptual and subjective parameters of the voice, while the examined person performs the following vocal tasks during voice recording:

- maximum phonation times (/a:/, /s:/, /z:/),
- uninterrupted phonation of a high-quality /a:/ in habitual voice for 3–4 s,
- glissando on phoneme /a:/ from lowest to highest frequency,
- continuous phonation of the phoneme /a:/ with continuous change of volume from natural volume to minimum volume,
- reading a standardized text in habitual voice.

The aerodynamic evaluation consists of determining the maximum phonation times (MPT) for three phonemes – /a:/, /s:/, and /z:/. The maximum phonation time is recorded as the length of continuous phonation in seconds. As part of the acoustic analysis, the following parameters are calculated from the continuous phonation of /a:/ in habitual voice: jitter (%), shimmer (%), glottal-to-noise-excitation (dB), and smoothed cepstral peak prominence (dB). From the glissando task, the lowest frequency (Hz), the highest frequency (Hz), and the frequency range in semitones are calculated. From the phonation of /a:/ at decreasing intensity, the minimum volume is calculated. Selected parameters of acoustic analysis are then used to calculate the Dysphonia Severity Index (DSI), which objectively quantifies the perceived voice quality (Wuyts, 2000). For auditory-perceptual assessment of the voice, a recording of the patient's reading of a standardized text is used, from which the GRB score is evaluated, i.e. the total degree of dysphonia (G), roughness (R), and breathiness (B) (Hirano, 1981). Subjective assessment of the patient's voice is carried out through the Slovak version of the Voice Handicap Index-30 (VHI-30) (Frajková, 2022).

### *Statistical methods*

The obtained data were recorded using MS Excel and then processed as part of a quantitative analysis by the free open-source statistical program JASP (version 0.16.4.0).

The demographic characteristics of the research cohort, specifically age and sex, were summarized using descriptive statistics. Descriptive statistics methods were used to summarize the results of the preoperative and postoperative assessments. The minimum and maximum, mean, median, and standard deviation data values were calculated. The Shapiro-Wilk normality test was used to determine the normality of the distribution of the data obtained. The findings of the "Voice Examination Protocol" obtained during the preoperative and postoperative examination were compared using the nonparametric Wilcoxon signed-rank test designed to compare the performance of the same group of respondents under two conditions.

## Research findings

The results of the preoperative "Voice Examination Protocol" are summarised in Table 1, while the results of the postoperative "Voice Examination Protocol" can be found in Table 2.

| | Valid data | Missing data | Median | Mean | SD | Minimum | Maximum |
|---|---|---|---|---|---|---|---|
| G | 30 | 0 | 3 | 2 | 1 | 0 | 3 |
| R | 30 | 0 | 1 | 1 | 1 | 0 | 3 |
| B | 30 | 0 | 2 | 2 | 1 | 0 | 3 |
| Jitter (%) | 30 | 0 | 4.55 | 7.34 | 6.54 | 0.12 | 18.27 |
| Shimmer (%) | 30 | 0 | 22.13 | 24.69 | 10.37 | 10.29 | 48.54 |
| GNE (dB) | 29 | 1 | 0.24 | 0.28 | 0.15 | 0.11 | 0.80 |
| Min. frequency (Hz) | 21 | 9 | 150.00 | 168.33 | 67.55 | 65.00 | 387.00 |
| Max. frequency (Hz) | 20 | 10 | 310.50 | 331.45 | 108.34 | 168.00 | 59.00 |
| Frequency range (ST) | 24 | 6 | 12 | 11 | 8 | 0 | 28 |
| CPPS (dB) | 30 | 0 | 7.29 | 8.16 | 3.93 | 3.23 | 16.74 |
| Min. volume (dB) | 28 | 2 | 49.0 | 50.1 | 8.8 | 34.0 | 68.0 |
| MPT /a:/ (s) | 29 | 1 | 8.4 | 7.2 | 4.0 | 0.0 | 15.6 |
| MPT /s:/ (s) | 30 | 0 | 13.6 | 14.1 | 5.4 | 4.3 | 27.0 |
| MPT /z:/ (s) | 28 | 2 | 7.5 | 7.3 | 4.5 | 0.0 | 20.8 |
| DSI value | 27 | 3 | −2,1 | 1.9 | 27.7 | −17.8 | 118.0 |
| DSI level | 25 | 5 | 0 | 1 | 2 | 0 | 5 |
| VHI – total score | 30 | 0 | 65 | 68 | 24 | 26 | 118 |

*Table 1:* ***Descriptive statistics of the preoperative "Voice Examination Protocol"***

| | Valid data | Missing data | Median | Mean | SD | Minimum | Maximum |
|---|---|---|---|---|---|---|---|
| G | 30 | 0 | 1 | 1 | 1 | 0 | 3 |
| R | 30 | 0 | 1 | 1 | 1 | 0 | 3 |
| B | 30 | 0 | 1 | 1 | 1 | 0 | 3 |
| Jitter (%) | 30 | 0 | 0.47 | 3.33 | 4.86 | 0.11 | 14.49 |
| Shimmer (%) | 30 | 0 | 15.66 | 17.95 | 8.47 | 4.14 | 36.97 |
| GNE (dB) | 30 | 0 | 0.47 | 0.43 | 0.24 | 0.11 | 0.87 |
| Min. frequency (Hz) | 27 | 3 | 117 | 136 | 59 | 51 | 269 |
| Max. frequency (Hz) | 27 | 3 | 319 | 336 | 118 | 157 | 595 |
| Frequency range (ST) | 30 | 0 | 15 | 15 | 9 | 0 | 34 |
| CPPS (dB) | 29 | 1 | 9.24 | 9.53 | 3.47 | 2.56 | 16.67 |
| Min. volume (dB) | 30 | 0 | 56 | 53 | 9 | 38 | 75 |
| MPT /a:/ (s) | 30 | 0 | 9.4 | 9.8 | 4.2 | 2.2 | 20.0 |
| MPT /s:/ (s) | 30 | 0 | 11.7 | 13.1 | 6.1 | 3.7 | 33.0 |
| MPT /z:/ (s) | 30 | 0 | 9.7 | 10.5 | 5.0 | 3.1 | 22.0 |
| DSI value | 30 | 0 | −1.0 | −2.3 | 5.5 | −16.0 | 6.1 |
| DSI level | 30 | 0 | 1 | 1 | 2 | 0 | 5 |
| VHI – total score | 28 | 2 | 34 | 40 | 27 | 0 | 110 |

*Table 2:* ***Descriptive statistics of the preoperative "Voice Examination Protocol"***

The effect of the augmentation procedure on the voice quality of the patients with unilateral vocal fold paralysis was evaluated by comparing the results of preoperative and postoperative voice examinations. The findings were compared using a non-parametric Wilcoxon signed-rank test due to the non-normal distribution of the data. We considered the differences between performances to be significant at the $p<0.05$ level of statistical significance. A statistically significant difference occurred in each of the areas of voice evaluation (auditory-perceptual, acoustic, aerodynamic, subjective), but only in nine parameters. Effect size was assessed using ordinal biserial correlation (r). Effect size values achieve statistically significant differences for all parameters except maximum frequency, minimum volume and DSI, with some parameters reaching values above 0.3 (moderate differences) and others values above 0.5 (large differences). The statistical significance and effect size findings are presented in Table 3.

| Preoperative assessment | Postoperative assessment | W | z | p | Rank-Biserial Correlation |
|---|---|---|---|---|---|
| G | G | 245 | 3.847 | <0.001 | 0.937 |
| R | R | 150 | 1.68 | 0.082 | 0.429 |
| B | B | 309 | 3.942 | <0.001 | 0.902 |
| Jitter (%) | Jitter (%) | 378 | 2.993 | 0.002 | 0.626 |
| Shimmer (%) | Shimmer (%) | 386 | 3.157 | 0.001 | 0.66 |
| GNE (dB) | GNE (dB) | 47 | −3.412 | <0.001 | −0.751 |
| Min. frequency (Hz) | Min. frequency (Hz) | 176 | 2.103 | 0.037 | 0.524 |
| Max. frequency (Hz) | Max. frequency (Hz) | 107.5 | 0.093 | 0.940 | 0.024 |
| Frequency range (ST) | Frequency range (ST) | 65.5 | −1.475 | 0.145 | −0.376 |
| CPPS (dB) | CPPS (dB) | 129.5 | −1.903 | 0.058 | −0.405 |
| Min. volume (dB) | Min. volume (dB) | 152 | −1.161 | 0.250 | −0.251 |
| MPT /a:/ (s) | MPT /a:/ (s) | 47.5 | −3.541 | <0.001 | −0.766 |
| MPT /s:/ (s) | MPT /s:/ (s) | 308 | 1.553 | 0.124 | 0.325 |
| MPT /z:/ (s) | MPT /z:/ (s) | 49 | −3.507 | <0.001 | −0.759 |
| DSI value | DSI value | 137 | −1.249 | 0.220 | −0.275 |
| DSI level | DSI level | 58.5 | −1.176 | 0.242 | −0.316 |
| VHI – total score | VHI – total score | 339 | 4.153 | <0.001 | 0.932 |

Note: W = Wilcoxon test, z = z-score, p = statistical significance, r = material significance

*Table 3:* ***Comparison of patient outcomes in preoperative and postoperative assessment***

## Discussion

The findings of this study indicate significant changes in the voice quality of patients with unilateral vocal fold paralysis after injection augmentation in the following parameters of voice analysis: overall voice quality and breathiness, jitter, shimmer, glottal-to-noise excitation, lowest voice frequency, maximum phonation time /a:/ and /z:/, and total VHI-30 score in the patient's subjective assessment.

Since the goal of the augmentation procedure is to improve glottic insufficiency and thus mitigate air leakage through the glottis, this procedure will naturally lead to a decrease in the breathiness parameter in the auditory-perceptual assessment, and consequently a decrease in the overall perceived level of dysphonia. A decrease in jitter and shimmer values in acoustic analysis indicates that vocal fold oscillation is more regular after the procedure, which is again a direct consequence of improved glottic closure and reduced airflow turbulence. From the aerodynamic analysis, the maximum phonation times of the voiced sounds /a:/ and /z:/ are a key clinical indicator, as the improvement in glottic closure optimizes pulmonary airflow efficiency, which extendes phontion duration. Thus, an improvement in MPT at /a:/ and /z:/ is expected, while an unchanged MPT value of /s:/ is of /s:/ confirms that the clinical improvement stems specifically from enhanced laryngeal insufficiency repair rather than a simple increase in respiratory support. A decrease in the VHI-30 score in the subjective assessment of the patient indicates a significant positive effect of the augmentation procedure on the patient's subjective well-being and quality of life.

Comparable results were found in a systematic review comparing the frequency of use and the relevance of different voice analysis parameters, in terms of significance of change in preoperative and postoperative measurements used to evaluate the treatment of unilateral vocal fold paralysis. The authors consider the most relevant parameters to be the maximum phonation times, auditory-perceptual assessment by the GRBAS scale, glottal-to-noise ratio (GNE), jitter, shimmer, and subjective evaluation by the VHI-30 questionnaire. The authors also consider the mean airflow rate, which was not evaluated in our study, to be a suitable diagnostic parameter (Desuter, 2018).

The findings of our study also point to the appropriateness of a comprehensive voice examination covering different areas – auditory-perceptual, acoustic, aerodynamic and subjective, as recommended in the Basic Protocol for Functional Voice Assessment of the European Laryngological Society (Dejonckere et al., 2001) and the Consensus for Voice Quality Assessment in Clinical Practice: Guidelines of the European Laryngological Society and Union of the European Phoniatricians (Lechien, 2023). In each of the recommended areas, at least one measured parameter came out as statistically significant with large effect size.

In this study, the findings of the "Voice Examination Protocol" were statistically analysed exclusively in patients with unilateral vocal fold paralysis undergoing unilateral injection augmentation with RenúVoice (*calcium hydroxylapatite*). However, the same protocol can be used in clinical practice in patients with a different type of paralysis (e.g. bilateral vocal fold paralysis), a different etiology in which the effectiveness of injection augmentation to improve voice quality has been verified (e.g. vocal fold atrophy), another injected substance (e.g. autologous fat), or in patients undergoing a different type of microlaryngosurgical procedure (e.g. thyroplasty I).

This study has several limitations. The first is the relatively small size of the research sample consisting of 30 participants, which limits the generalizability of the findings to a wider population of patients with unilateral vocal fold paralysis. The immeasurability of certain parameters of voice analysis in some types of dysphonia (e.g. the impossibility of measuring the maximum phonation time for a voiced sound in

aphonia) caused a relatively large number of missing data in the statistical analysis. Since the study compared postoperative outcomes after two weeks, there is a lack of information as to the long-term effect of the augmentation procedure. Data collecting from voice examination 12 months after the procedure would allow assessment of the long-term dynamics of changes in voice parameters. Since the different etiological factors of unilateral vocal fold paralysis and its duration may have an impact on treatment outcomes, it would be appropriate to take these parameters into account in the future as part of the statistical analysis. Follow-up research could also include comparing the results with a control group of patients undergoing a different treatment modality (e.g. voice therapy only).

## Summary

The findings of this study indicate significant changes in the voice quality of patients with unilateral vocal fold paralysis after injection augmentation in the following parameters of voice analysis: overall voice quality and breathiness, jitter, shimmer, glottal-to-noise excitation, lowest voice frequency, maximum phonation time /a:/ and /z:/, and total VHI-30 score in the patient's subjective assessment. Based on the results of the study, we consider auditory-perceptual assessment (GRBAS scale), aerodynamic measurements (maximum phonation times), acoustic analysis (jitter, shimmer, GNE) and subjective assessment of the patient's voice (VHI-30 questionnaire) to be relevant parameters in the preoperative and postoperative evaluation of voice quality of patients undergoing phonosurgical treatment due to unilateral vocal fold paralysis. A diagnostic protocol including these voice parameters will provide standardized voice evaluation, enable objective evaluation of the effectiveness of vocal fold augmentation, help guide clinical decision-making on the management of patients with vocal fold paralysis and, last but not least, enable consistent collection of data on patients undergoing vocal fold augmentation.

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