Voice outcome following electrical stimulation-supported voice therapy in cases of unilateral vocal fold paralysis

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Introduction
The current lack of knowledge on the effects of transcutaneous electrical stimulation-supported voice therapy (TESVT) on voice production, coupled with increasing anecdotal reports of TESVT use with voice disorders, prompted this research.

Aim
The aim of this study was to compare the therapeutic value of conventional voice therapy (CVT) and TESVT on voice outcome in patients with unilateral vocal fold paralysis.

Patients and methods
The study was conducted on randomly selected 29 patients with unilateral vocal fold paralysis who were candidates for voice therapy attending to the Unit of Phoniatrics, Department of Otorhinolaryngology, Faculty of Medicine, University of Alexandria. The patients were divided into two groups: group I, which included 14 patients who were assigned to CVT, and group II, which included 15 patients who were assigned to TESVT.

Each patient was subjected to the following procedures before and after therapy to document glottis closure and voice quality changes: auditory perceptual assessment using the GRBAS scale, the Voice Problem Self-assessment Scale, videostroboscopic examination, and acoustic and aerodynamic analysis of a sample of phonation in addition to electroglottography. TESVT was applied for all participants.

Results
Statistically significant changes have been obtained for all measurers. No significant statistical difference was found between CVT and TESVT in patients with vocal fold immobility except for frequency perturbation and some electroglottographic parameters.

Conclusion
Transcutaneous electrical stimulation-supported voice therapy is as effective as CVT in improving voice parameters in cases of unilateral vocal fold immobility. Further research is warranted with a larger number of patients to assess the efficacy of electrical stimulation-supported voice therapy in cases of vocal fold immobility and to determine selective criteria for this TESVT approach.

Keywords:
electric stimulation, unilateral vocal fold paralysis, voice therapy

Introduction
The concept of 'voice therapy' has gained a well-defined place in voice disorder management [1]. Voice therapy in vocal fold immobility is typically directed at abdominal breathing and humming/resonant voice to improve closure of the glottis, encourage abdominal breath support, and improve vocal function, intrinsic laryngeal muscle strength, and agility while avoiding supraglottic hyperfunction [2–4].

The goal of electrical stimulation-supported voice therapy is, on the one hand, to achieve, with individually adapted stimulation current strength during intended phonation, a return of nerve function 'regeneration efficiency', likely an acceleration of 'natural' regeneration. On the other hand, electrical stimulation can protect a denervated muscle against muscle deterioration, such as atrophy and fibrillations 'protection effect' [5].

Pahn and Pahn [6] introduced the concept of neuromuscular electrophonatory stimulation (NMEPS) in which the patient performs voice exercises together

with single stimulation pulses. The principle idea of electrical stimulation therapy for regeneration and protection is that only damaged muscles are stimulated – that is, damaged muscles are forced to contract with a current pulse. The healthy muscles, however, are not stimulated. The stimulation is performed generally with electrodes placed on the skin. Neuromuscular electrical stimulation (NMES) is postulated to improve hyolaryngeal elevation, restore motor function of weak muscles, combat disuse atrophy, enhance sensory awareness, and facilitate muscle contractions [7,8]. NMES recruits more units compared with volitional contraction and may produce greater gains in muscle strength compared with exercise alone [9]. Recent studies have reported that presenting transcutaneous neuromuscular stimulation in conjunction with voluntary contraction results in the recruitment of a greater number of the fast twitch type II muscle fibers that are responsible primarily for fast contraction velocities [10]. Type II muscle fibers are more abundantly used for swallowing and voicing compared with type I muscle fibers in healthy individuals [11]. Type II muscles are more prone to muscle disuse atrophy compared with slow-twitch muscle fibers (type I) [12]. During normal muscle contraction, type I fibers are recruited first followed by type II fibers; however, during transcutaneous electrical stimulation (TES) treatment, type II fibers are recruited first followed by type I fibers [13,14]. If voice therapy is combined with electrostimulation therapy, all three aspects – namely, regeneration, protection, and compensation – will be addressed [5].

The current lack of knowledge on the effects of transcutaneous electrical stimulation-supported voice therapy (TESVT) on voice production, coupled with increasing anecdotal reports of TESVT use with voice disorders, prompted this research.

Aim
The aim of this work was to compare the therapeutic value of conventional voice therapy (CVT) and TESVT on voice outcome in patients with unilateral vocal fold paralysis (UVFP).

Patients and methods
The study was conducted on randomly selected 29 patients with UVFP who were candidates for voice therapy, with minimal glottis gap subjectively estimated to be less 2 mm, attending the Unit of Phoniatrics, Department of Otorhinolaryngology, Faculty of Medicine, University of Alexandria. The patients were

divided into two groups: group I included 14 patients who were assigned to CVT, and group II included 15 patients who were assigned to electrical stimulation-supported voice therapy. The small number of participants was verified by the uncertainty of the therapy outcome of TESVT as a new method of intervention. Therapy was performed for 16 sessions. All participants were required to sign a letter of consent. The IRB/Ethics committee approved the current research.

Exclusion criteria were as follows:

(1) Previous voice therapy or any other therapy.
(2) Immobility onset more than 6 months before therapy.
(3) Presence of other conditions possibly interfering with the therapy, such as tracheotomy or other serious diseases.

Each patient was subjected to the following procedures before and after therapy to document glottis closure and voice quality changes:

(1) Auditory perceptual assessment using the GRBAS scale performed by three judges [15].
(2) Voice Problem Self-assessment Scale (VPSS) questionnaire [16].
(3) Videostroboscopic examination of the glottis using a Kay Pentax stroboscope (Lincoln Park, NJ, USA) before therapy and repeated after 3 months to detect any signs of recovery. Examinations were videotaped for further interpretation and for calculation of the glottis gap index using Kay's Image Processing Software.
(4) Acoustic analysis of a sample of phonation using the Multidimensional Voice Program (model 5105, 2001; Kay Elemetrics, Lincoln Park, NJ, USA).
(5) Aerodynamic measurements using the Voice Function Analyzer Aerophone II Software (model 6800, Lincoln Park, NJ, USA).
(6) Electroglottography (EGG) using KayPentax Real-Time EGG Analysis software (model 5138). Data were captured when the patient was phonating /a/ at a habitual pitch and loudness with the EGG electrodes placed over each side of the thyroid cartilage.
(7) Laryngeal electromyography using the Nihon Kohden electromyographic apparatus (Rosbach V.d.H, Germany) to exclude mechanical fixation.
(8) Voice therapy.

Patients in group I received voice therapy sessions, each 20 min in duration, twice a week for 12 sessions. CVT steps included the following:

(1) Accent method of voice therapy: Therapy consisted of the following steps:

(a) Diaphragmatic breathing: The patients are trained in the sitting position, except in a few rigid patients in whom the training starts in the supine position. Relaxation of the upper chest and shoulders is assured while transferring all respiratory efforts to the abdominal level.

(b) Phonatory exercises: The phonatory phase (vowel play) were practiced in the different rhythms. Using the newly acquired diaphragmatic breathing, the patient is allowed to 'sing' the various vowels at a slow '3/4, largo' rhythm to produce an accentuated final, long, relaxed phonation. Faster rhythm '4/4, andante' and later double speed '4/4, allegro' rhythms are introduced, aiming at the production of repeated short phonations with an increasing length of the series of utterances. This stage of the training program continues with interplay of the different rhythmic types.

(c) Transfer to connected speech: As soon as the patient reaches a reasonable control of the goals of stage 2, simple articulated speech utterances are introduced, to be repeated and copied by the patient. Gradually, the transformation to connected speech advances until the major part of the session is invested in increasing spontaneous speech activities using the newly acquired accentuated phonatory respiratory techniques. The following steps will lead the patient to the ultimate goal of using the newly acquired vocal habits in spontaneous dialog through tasks of gradually increasing difficulty:

(i) Articulated vocal play of nonsense syllables.
(ii) Repetition of the therapist's speech utterances.
(iii) Reading aloud.
(iv) Monologue [1].

(2) Hard glottal attacks: In cases with gaps of 2 mm, phonation during pushing movements of the upper limbs to achieve voice sonority during effort closure of the larynx were practiced at the beginning of the therapy session (pushing exercises were performed in selected cases, due to risk for mucosal injury and development of hyperfunctional compensation).

Patients in group II received TESVT:

(1) Standardized therapy with NMEPS according to Pahn and Pahn [6] is based on electrostimulation of the damaged musculature in the form of intentional exercises. While the patient attempts to trigger voluntary contraction, at the same time, a supporting electric pulse is triggered manually by means of a manual release key.

(2) Patients received TESVT sessions using VocaSTIM systems (PHYSIOMED ELEKTROMEDIZIN AG Hutweide 10 91220 Schnaittach, Germany), as shown in Fig. 1. VocaSTIM stands for a new therapy concept for larynx paresis, dysphagia, and various other peripheral and central paresis in the areas of the larynx and face. VocaSTIM is claimed to be the efficient therapy concept for diagnosis, therapy, therapy process control, and autonomous therapy/autonomous voice training of the patient. The electrotherapy treatment unit with VocaSTIM consists of two sequences:

(a) Preheating with appropriate current types for promoting blood circulation.
(b) Actual NMEPS/electroarticulatory stimulation with appropriate pulses.

(3) The skin in the laryngeal and submental areas was cleaned with alcohol to increase adherence of the bipolar electrodes to the skin (Fig. 2). A large indifferent electrode was attached to the nape, and a small electrode serving as different electrode is placed on either side of the thyroid lamina just below the thyroid notch [17]. All stimuli were exponential currents with a 240 ms duration. The intensity was raised gradually in 0.5 mA steps until the patient indicated that any further increase would become uncomfortable.

(4) Voice therapy sessions were carried out twice weekly for 12 sessions with a duration of 20 min. Voice therapy steps included the following:

(a) Abdominal breathing training: The patients are trained in the sitting position. Relaxation of the upper chest and shoulders is assured while transferring all respiratory efforts to the abdominal level.

Figure 1

The VocaSTIM unit.
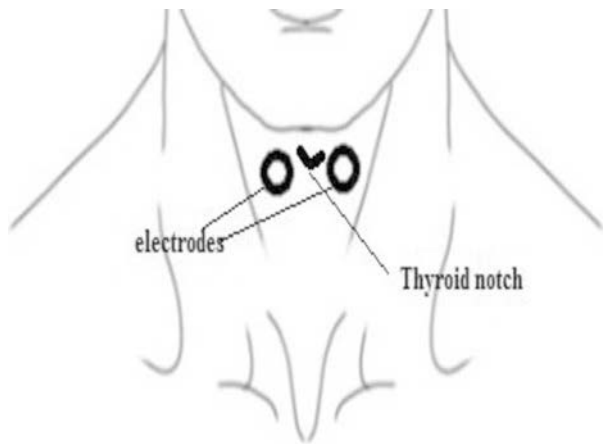
The placement of the electrodes in submental region.

(b) Voice function exercises synchronized with the manual triggering of electrostimulation: The following vocal exercises are used:

(1) Emission of vowels (/a/, /ä/, /i/, /o/): It is carried out first quietly, at constant pitch. Vowels are short with soft glottal attack. Loudness is gradually increased with falling pitch. Prolonged vowels are used with increasing glottal attack.

(2) Emission of syllables (/am/, /äm/): Prolonged vowels are used with increasing glottal attack.

(3) Emission of bisyllables (/aha/, /oho/, /ihi/): It is carried out moderately loud with long second vowel at falling pitch.

(c) Emission of three to seven syllables (/ajaja/, /amama/): It is carried out from moderately loud to loud with varying pitch.

(d) Cough attack: The patient breaths is followed by a ceased respiration for a few seconds with a laryngeal contraction and an energic emission with a diaphragmatic support.

(e) Cough with vowel: The patient coughs and then releases a vowel (/i/, /e/, /a/, /o/).

(4) All vocal function exercises were carried out using a series of facilitations and included the following: pushing of the bust – the vocalization was uttered with a quick bending downward of the bust and with the arms folding into the shoulders; and pushing of the arms – the vocalization was uttered with a thrust forward of the arms. Facilitations could also be performed with a concurrent emission of vocalization while rising from a chair.

Statistical analysis

Data were fed to the computer and analyzed using IBM SPSS software package (version 20.0; IBM Corp., Armonk, NY). Comparison between the two studied groups as regards categorical variables was made using the χ^2-test. When more than 20% of the cells have expected count less than 5, correction for χ^2 was conducted using Fisher's exact test or Monte Carlo correction. However, the McNemar–Bowker test was used to analyze the significance between pretherapy and post-therapy changes.

The Wilcoxon signed-rank test was used to compare pretherapy and post-therapy changes. The McNemar–Bowker test was used to analyze the significance between pretherapy and post-therapy changes.

Results

Table 1 shows the distribution of studied groups according to age, sex, cause of UVFP, and duration of symptoms. There was no significant statistical difference between the two groups as regards previous variables. Pretherapy assessment revealed no significant statistical difference between the two groups as regards all studied parameters (Tables 2–6).

The study revealed post-therapeutic significant statistical improvement in the GRBAS scores and total VPSS and cluster scores in both groups. No significant difference in post-therapy between group I and group II was recorded (Table 2).

Follow-up stroboscopic examination of patients after 12 sessions of therapy revealed significant statistical difference between pretherapeutic and post-therapeutic glottis closure, but none of the patients regained mobility of the affected vocal fold in both groups. There was significant statistical difference between pretherapeutic and post-therapeutic values for the glottal gap index in both groups. No significant statistical difference was found between the studied groups as regards their post-therapy values (Table 3).

On comparing the acoustic parameters obtained from patients before and after therapy, there was a significant statistical difference as regards frequency and amplitude perturbation analysis. The voice break analysis parameter of degree of unvoiced as well as the noise-related parameters [voice turbulence index (VTI) and soft phonation index (SPI)] also showed significant statistical difference between the two groups. Comparison of both groups post-therapeutically revealed significant statistical improvement in group II as regards frequency

Table 1 Comparison between the studied groups according to demographic data

	CVT (n=14) [N (%)]	TESVT (n=15) [N (%)]	Test of significance	P
Sex				
Male	5 (33.3)	2 (13.3)	χ^2=1.677	P=0.390 (FE)
Female	10 (66.7)	13 (86.7)		
Age				
Min.–max.	17.0–59.0	25.0–57.0	Z=0.499	0.618
Mean±SD	39.67±12.79	42.40±11.39		
Median	40.0	45.0		
Etiology				
Thyroidectomy	10 (66.7)	8 (53.3)	χ^2=1.365	P=0.869 (MC)
Viral infection	2 (13.3)	2 (13.3)		
Idiopathic	3 (20.0)	4 (26.7)		
Blunt trauma	0 (0.0)	1 (6.7)		
Duration of symptoms				
Min.–max.	0.50–6.0	1.0–6.0	Z=0.296	0.767
Mean±SD	3.03±1.63	2.87±1.92		
Median	3.0	2.0		

CVT, conventional voice therapy; FE, Fisher exact test; MC, Monte Carlo test; min., minimum; max., maximum; TESVT, transcutaneous electrical stimulation-supported voice therapy; Z, Mann–Whitney test.

perturbation analysis [absolute jitter, jitter percent, relative average perturbation, pitch perturbation quotient, and smoothed pitch perturbation quotient], whereas there was no significant statistical difference as regards frequency variation (vF0). No significant statistical difference was found between the two groups as regards the rest of acoustic parameters. Statistically significant elevation of lowest fundamental frequency (Flo) values in the electrical stimulation-supported voice therapy group was noticed after therapy (Table 4).

Comparison of aerodynamic analysis results pretherapeutically and post-therapeutically revealed a statistically significant decrease in the maximum flow rate, volume, mean airflow rate, peak and mean air pressure, mean power, and phonation quotient. Meanwhile, there was a statistically significant increase in the mean efficiency, mean resistance, vital capacity, and maximum phonation time (MPT) in both groups. There was no significant statistical difference as regards post-therapeutic values between the two groups (Table 5).

On comparing the time-based parameters obtained with EGG (contact quotient, open quotient, opening quotient, closing quotient, and speed quotient) pretherapeutically and post-therapeutically, there was a significant statistical difference in all parameters between the two groups. Comparison of post-therapeutic values between the two groups revealed a significant statistical difference as regards the contact, the open, and the speed quotient. No statistically significant difference was found between the two groups as regards opening and closing quotients (Table 6).

Discussion

Voice therapy is the main nonsurgical management option for such patients with vocal fold paralysis [4,18]. Combining exercise with adjunctive electrical stimulation may enhance the positive effects of voice therapy. This combined approach, until recently, had not been tested in rehabilitation of any pathologic laryngeal condition [19–21].

The voice quality of patients was judged as breathy and rough, with a moderate overall grade of dysphonia before therapy. The mean values of asthenia and strained parameter were high in the post-therapy assessment, probably because the glottal insufficiency often gives the impression of asthenicity even if a strain is present. A general reduction in severity was found for all parameters after therapy; the difference was statistically significant.

Patient perception scales are used to clarify the patient's concerns and to show change over time or as a result of intervention. The purpose of the therapy is to address the symptoms that bother the patient. In the present study, self-assessment measures using the VPSS showed a significant improvement in total as well as different clusters, thus suggesting that quality of life reaches a more satisfactory level after the voice therapy program. Similarly, in the series by Schindler et al. [22] and Mattioli et al. [23], an improvement was found for voice handicap index values. Moreover, for the total

Table 2 The auditory perceptual assessment using the GRBAS scale for the two studied groups before and after therapy and patient's self-evaluation of dysphonia using the Voice Problem Self-assessment Scale

	Pretherapy		Post-therapy		P_1	P_2
	CVT	TESVT	CVT	TESVT		
GRBAS scale						
G						
Min.–max.	1.0–3.0	1.0–3.0	0.0–3.0	0.0–2.0	0.004**	0.001***
Mean±SD	2.0±0.65	2.13±0.52	0.93±0.88	0.87±0.74		
Median	0.65	2.0	1.0	1.0		
P		0.550		0.946		
R						
Min.–max.	0.0–1.0	0.0–1.0	0.0–0.0	0.0–1.0	0.008**	0.014*
Mean±SD	0.47±0.52	0.60±0.51	0.0±0.0	0.20±0.41		
Median	0.0	1.0	0.0	0.0		
P		0.472		0.073		
B						
Min.–max.	1.0–3.0	1.0–3.0	0.0–2.0	0.0–2.0	0.001***	0.001***
Mean±SD	2.0±0.53	2.07±0.59	0.60±0.74	0.60±0.83		
Median	2.0	2.0	0.0	0.0		
P		0.738		0.889		
A						
Min.–max.	0.0–2.0	0.0–3.0	0.0–2.0	0.0–1.0	0.014*	0.046*
Mean±SD	0.87±0.74	0.93±0.88	0.47±0.64	0.60±0.51		
Median	1.0	1.0	0.0	1.0		
P		0.946		0.396		
S						
Min.–max.	0.0–3.0	0.0–3.0	0.0–2.0	0.0–2.0	0.014*	0.008**
Mean±SD	0.67±0.82	1.0±1.07	0.27±0.59	0.33±0.62		
Median	1.0	1.0	0.0	0.0		
P		0.419		0.694		
VPSS						
Functional						
Min.–max.	5.0–20.0	5.0–20.0	0.0–18.0	2.0–10.0	0.001***	0.001***
Mean±SD	14.0±5.40	13.0±4.24	6.13±5.84	5.20±2.88		
Median	15.0	13.0	4.0	4.0		
P		0.441		0.772		
Physical						
Min.–max.	2.0–20.0	20.0–14.5	1.0–16.0	3.0–12.0	0.001***	0.001***
Mean±SD	13.9±4.3	14.5±2.8	8.13±3.83	7.8±2.88		
Median	14.0	14.0	7.0	8.0		
P		0.557		0.835		
Emotional						
Min.–max.	7.0–18.0	4.0–20.0	1.0–15.0	0.0–9.0	0.001***	0.001***
Mean±SD	12.07±3.33	11.27±4.45	4.73±3.97	2.87±2.70		
Median	12.0	11.0	3.0	2.0		
P		0.505		0.167		
Phonasthenic						
Min.–max.	2.0–20.0	5.0–20.0	0.0–19.0	2.0–10.0	0.001***	0.001***
Mean±SD	12.13±5.64	13.20±4.41	6.20±5.67	6.47±3.0		
Median	11.0	12.0	5.0	8.0		
P		0.661		0.277		
Total						
Min.–max.	17.0–80.0	33.0–80.0	8.0–63.0	9.0–40.0	0.001***	0.001***
Mean±SD	52.13±14.5	52.0±11.62	25.2±17.27	22.33±10.2		
Median	53.0	52.0	20.0	24.0		
P		0.603		0.917		

A, asthenia; B, breathiness; CVT, conventional voice therapy; G, overall grade of dysphonia; min., minimum; max., maximum; MC, monte carlo test; R, rouphness; S, strained; TESVT, transcutaneous electrical stimulation-supported voice therapy; VPSS, Voice Problem Self-assessment Scale. *P*, *P* value for the Mann–Whitney test comparing between the two studied groups. P_1, *P* value for the Wilcoxon signed-rank test for comparing between pretherapy and post-therapy values in the CVT group. P_2, *P* value for the Wilcoxon signed-rank test for comparing between pretherapy and post-therapy values in the EVT TESVT group. *Statistically significant at *P*≤0.05. **Statistically significant at *P*≤0.01. ***Statistically significant at *P*≤0.001.

Table 3 Comparison between the studied groups according to stroboscopic findings and the glottal gap index before and after therapy

	Pretherapy [N (%)]		Post-therapy [N (%)]		P_1	P_2
	CVT	TESVT	CVT	TESVT		
Symmetry						
Symmetric	8 (53.3)	6 (40.0)	11 (73.3)	10 (66.7)	0.250	0.125
Asymmetric	7 (46.7)	9 (60.0)	4 (26.7)	5 (33.3)		
P	$P=0.464$ (χ^2)		$P=1.000$ (FE)			
Amplitude						
Normal	9 (60.0)	4 (26.7)	10 (66.7)	8 (53.3)	1.000	0.063
Decrease	6 (40.0)	11 (73.3)	5 (33.3)	7 (46.7)		
P	$P=0.065$ (χ^2)		–			
Periodicity						
Regular	8 (53.3)	6 (40.0)	12 (80.0)	11 (73.3)	0.125	0.063
Irregular	7 (46.7)	9 (60.0)	3 (20.0)	4 (26.7)		
P	$P=0.464$ (χ^2)		$P=1.000$ (FE)			
Glottic closure						
Complete	0 (0.0)	0 (0.0)	10 (66.7)	9 (60.0)	0.001[***]	0.001[***]
Incomplete	15 (100.0)	15 (100.0)	5 (33.3)	6 (40.0)		
P	–		$P=1.000$ (FE)			
Supraglottic activity						
Absent	9 (60.0)	9 (60.0)	10 (66.7)	12 (80.0)	1.000	0.250
Present	6 (40.0)	6 (40.0)	5 (33.3)	3 (20.0)		
P	$P=1.000$ (χ^2)		$P=0.682$ (FE)			
Glottal gap index						
Min.–max.	0.10–0.30	0.10–0.30	0.0–0.30	0.0–0.30	$P_1<0.001$[***] (t)	$P_2<0.001$[***] (t)
Mean±SD	0.17±0.09	0.19±0.09	0.07±0.10	0.08±0.12		
Median	0.10	0.20	0.0	0.0		
P	$P_1=0.688$ (t)		$P_1=0.749$ (t)			

FE: Fisher exact test; CVT, conventional voice therapy; min., minimum; max., maximum; TESVT, transcutaneous electrical stimulation-supported voice therapy. P_1, P value for the McNemar test for comparing between pretherapy and post-therapy values in the CVT group. P_2, P value for the McNemar test for comparing between pretherapy and post-therapy values in the TESVT group. ***Statistically significant at $P\leq0.001$.

values as well as for the physical, functional, and emotional subscales, improvement was found and the differences were significant [22,23].

At follow-up after 12 sessions, a significant statistical improvement in glottal closure was encountered in 67% of group I patients and 60% of group II patients. Different factors are involved in glottal closure improvement; for instance, the interarytenoid muscles, which are supplied by both the left and the right recurrent laryngeal nerves, have the possibility of adducting the vocal fold toward the midline. The action of the cricothyroid muscle may also help the medial movement of the vocal fold; finally, the inferior pharyngeal constrictor muscle, arising from the thyroid cartilage, may favor glottal closure [22].

Several clinical and instrumental indicators of improvement of glottis closure have been provided in the present study. Clinically, it was noticed that, even if the vocal fold immobility persisted in all participants examined, a general improvement in glottal closure was noticed. Similarly, in the study by Schindler *et al.* [22],

the vocal fold immobility persisted after voice therapy in all 40 patients included in the study.

Statistically significant changes in the glottal gap index tested before and after therapy were noticed. Humbert *et al.* [24] examined the effects of TESVT on vocal fold position; they showed a clinically nonsignificant change in vocal fold angle in the anterior commissure area of the vocal folds after transcutaneous electrical stimulation (TES) treatment. They stated that TES to the anterior neck stimulates the superficial musculature only and not the deeper muscles of the larynx, which provide the primary control for vocal fold adduction and stiffness [24].

Acoustically, this prospective case series demonstrated that the TESVT decreased significantly all frequency perturbation analyses and the amplitude perturbation analyses post-therapeutically. Reduction in the perturbation analysis parameters indicates improved ability of the vocal folds to support a periodic vibration for a defined period. Several studies reported that, in patients receiving electrical

Table 4 Comparison between the studied groups according to acoustic analysis

	Pretherapy		Post-therapy		P_1	P_2
	CVT	TESVT	CVT	TESVT		
Fundamental frequency						
FO (Hz)						
Mean±SD	204.0±53.8	209.1±67.6	204.2±56.1	224.8±46.5	0.865	0.173
P		0.950		0.310		
Fhi (Hz)						
Mean±SD	238.4±68.8	248.4±65.4	229.1±66.1	256.8±49.8	0.256	0.532
P		0.820		0.351		
Flo						
Mean±SD	165.8±58.9	174.7±50.6	167.0±69.6	199.4±40	0.496	0.041[*]
P		0.694		0.191		
PFR (Hz)						
Mean±SD	7.7±7.1	7.4±5.8	5.9±4.7	6.1±3.7	0.061	0.068
P		0.900		0.585		
Frequency perturbations analysis						
Jita%						
Mean±SD	170.7±181.1	153.3±116.1	107.1±61.5	67.11±28.73	0.005[**]	0.001[***]
P		0.950		0.049[*]		
Jitt%						
Mean±SD	3.3±2.9	2.8±1.4	1.5±0.8	0.88±0.39	0.001[***]	0.001[***]
P		0.950		0.015[*]		
RAP%						
Mean±SD	1.9±1.6	1.7±0.8	0.8±0.5	0.40–0.26	0.001[***]	0.001[***]
P		0.820		0.026[*]		
PPQ%						
Mean±SD	2.0±1.9	1.7±0.9	1.0±0.7	0.44±0.28	0.001[***]	0.001[***]
P		0.443		0.021[*]		
sPPQ						
Mean±SD	2.7±3.1	1.9±0.9	1.4±1.8	0.58±0.21	0.001[***]	0.001[***]
P		0.633		0.017[*]		
vF0%						
Mean±SD	7.4±11.7	4.7±4.5	4.0±6.4	1.38±2.24	0.001[***]	0.001[***]
P		0.917		0.033*		
Amplitude perturbations analysis						
ShdB%						
Mean±SD	0.6±0.5	0.5±0.4	0.3±0.3	0.2±0.1	0.001[***]	0.001[***]
P		0.836		0.724		
Shim%						
Mean±SD	6.2±5.5	6.1±4.6	3.6±2.9	3.3±3.4	0.001[***]	0.001[***]
P		0.724		0.724		
APQ%						
Mean±SD	4.6±4.8	4.2±3.0	2.7±2.6	2.1±2.2	0.001[***]	0.001[***]
P		0.820		0.340		
sAPQ						
Mean±SD	6.8±5.8	6.1±3.0	4.0±2.9	3.4±2.7	0.001[***]	0.001[***]
P		0.756		0.254		
vAm						
Mean±SD	17.7±7.5	18.8±7.1	9.2±3.9	9.8±3.7	0.001[***]	0.001[***]
P		0.633		0.548		
Voice breaks, harmonics, and voicing parameters						
DVB						
Mean±SD	1.59±6.16	0.80±2.83	1.03±3.98	0.20±0.78	0.317	0.180
P		0.605		0.962		
DSH						
Mean±SD	3.09±8.27	1.45±2.69	2.49±7.11	0.96±2.19	0.068	0.068
P		0.778		0.675		
DUV						

(Continued)

Table 4 (*Continued*)

| | Pretherapy | | Post-therapy | | P_1 | P_2 |
	CVT	TESVT	CVT	TESVT		
Mean±SD	8.93±18.71	11.71±19.06	2.40±5.45	2.50±6.53	0.008[**]	0.005[**]
P		0.704		0.815		
NHR						
Mean±SD	0.2±0.1	0.2±0.1	0.2±0.1	0.2±0.1	0.144	0.285
P		0.300		0.395		
VTI						
Mean±SD	0.05±0.02	0.05±0.01	0.04±0.02	0.04±0.01	0.033[*]	0.041[*]
P		0.561		0.851		
SPI						
Mean±SD	30.0±18.5	33.2±15.0	19.55±12.74	20.7±13.9	0.001[***]	0.009[**]
P		0.419		0.820		

CVT, conventional voice therapy; DSH, degree of subharmonics Subharmonics; DUV, degree of unvoiced; DVB, degree of voice breaks; Fo, funamental frequency; Flo, lowest fundamental frequency; Fhi, highest fundamental frequency; Jita, absolute jitter; Jitt, jitter percent; NHR, noice harmonic ratio; PFR, Phonatory frequency range; PPQ, pitch perturbation quotient; RAP, relative average perturbation; Shimmer in dB (ShimdB), shimmer percent (Shim). Amplitude (APQ) and smoothed amplitude perturbation Quotients (sAPQ); SPI, soft phonation index; sPPQ, smoothed pitch perturbation quotient; TESVT, transcutaneous electrical stimulation-supported voice therapy; vAm, variation of amplitude; vF0, frequency variation; VTI, voice turbulence index. P, P value for the Mann–Whitney test comparing between the two studied groups. P_1, P value for the Wilcoxon signed-rank test for comparing between pretherapy and post-therapy values in the VT group. P_2, P value for the Wilcoxon signed-rank test for comparing between pretherapy and post-therapy values in the EVT group. *Statistically significant at $P \leq 0.05$. **Statistically significant at $P \leq 0.01$. ***Statistically significant at $P \leq 0.001$.

stimulation-supported voice therapy, irregularity decreased significantly even more than that in the traditional voice therapy [25,26]. However, Ptok and Starck [27] reported slight, although not significant, differences favoring electrical stimulation-supported vocal exercises.

The decreased values of variation of amplitude (vAm) and vF0 clearly decreased after therapy related to the phonatory stability during a sustained vowel production. Both vAm and vF0 indices reflect a short-term and long-term vAm and vF0, respectively. Guzman *et al.* [28] reported a decrease in vAM and vF0 in two female patients receiving NMES in combination with voice therapy for rehabilitating dysphonia secondary to suspected superior laryngeal nerve weakness. The low fundamental frequency (FO) value changes in electrical stimulation-supported voice therapy showing post-therapeutic significance may signify increased stress and tenseness of external laryngeal muscles that indirectly act on the cricothyroid joint to alter the tension of the vocal fold. Decreased FO noticed after CVT reinforces the relaxation effect on external laryngeal musculature achieved with voice therapy [29].

Improvement of degree of unvoiced after TES indicates improved ability of voice to sustain uninterrupted voicing. The current study showed that the VTI and SPI showed a significant reduction reflecting improvement of glottis closure and reduction of incompetence. The VTI mostly correlates with the turbulence caused by incomplete

or loose adduction of the vocal folds. The parameter of SPI can be implied as sensitive to abnormalities in vocal fold adduction and a good indicator of breathiness [30]. Rigidity of vocal tract walls, vocal source, and weaker or less complete vocal fold closure affect the resultant spectral slope. Therefore, increased values of SPI are thought to indicate incomplete vocal fold adduction; thus, its reduction reflects decreased incompetence [31].

Comparison of acoustic parameters of both groups post-therapeutically revealed significant statistical improvement in group II as regards frequency perturbation analysis (absolute jitter, jitter percent, relative average perturbation, pitch perturbation quotient, and smoothed pitch perturbation quotient). These findings are in accordance with the results of several studies in the literature comparing the outcome of traditional voice exercise treatment with electrical stimulation-supported voice exercise in patients diagnosed with UVFP. The authors reported that, in the group receiving electrical stimulation-supported voice therapy, irregularity decreased significantly more than that in the traditional voice therapy group after a 3-month therapy period [23,26]. However, in another study, Ptok and Starck [27] reported slight, although not significant, differences favoring electrical stimulation-supported vocal exercises.

Aerodynamic measures improved significantly after TESVT similar to CVT techniques. Post-therapy evaluation showed a significant reduction in the flow

Table 5 Pretherapy and post-therapy aerodynamic analysis of both studied groups

	Pretherapy		Post-therapy		P_1	P_2
	CVT	TESVT	CVT	TESVT		
Vital capacity (l)						
Min.–max.	1.19–12.10	1.06–8.50	0.76–13.0	1.88–9.04	0.002**	0.001***
Mean±SD	5.47±3.37	3.83±2.19	6.39±3.49	4.93±2.07		
Median	4.88	3.09	5.22	5.65		
P		0.221		0.290		
MPT						
Min.–max.	2.0–7.0	2.0–8.0	5.0–17.0	5.0–20.0	0.001***	0.001***
Mean±SD	4.33±1.45	4.30±1.65	10.87±4.37	11.40±4.61		
Median	4.0	4.0	9.0	11.0		
P		0.832		0.835		
PQ						
Min.–max.	0.30–2.59	0.15–2.13	0.13–1.18	0.11–1.33	0.002**	0.001***
Mean±SD	1.32±0.76	1.04±0.66	0.62±0.30	0.51±0.32		
Median	1.25	1.0	0.65	0.43		
P		0.373		0.221		
Max. flow rate (l/s)						
Min.–max.	0.72–1.40	0.80–1.40	0.45–1.23	0.45–1.10	0.001***	0.001***
Mean±SD	1.13±0.23	1.03±0.22	0.83±0.22	0.72±0.21		
Median	1.19	0.96	0.88	0.69		
P		0.169		0.206		
Mean air flow rate (l/s)						
Min.–max.	0.20–0.79	0.42–0.63	0.11–0.54	0.11–0.34	0.001***	0.001***
Mean±SD	0.54±0.14	0.52±0.06	0.26±0.12	0.20±0.07		
Median	0.53	0.49	0.22	0.18		
P		0.648		0.147		
Max. SPL (dB)						
Min.–max.	80.1–100	83.9–95.0	83.9–94.7	80.7–94.3	0.233	0.443
Mean±SD	88.8±5.6	88.9±3.68	87.5±3.0	88.0±3.14		
Median	89.0	88.8	86.60	88.60		
P		0.885		0.262		
Mean SPL (dB)						
Min.–max.	66.1–85.4	71.7–83.9	68.8–80.4	70.5–83.7	0.173	0.443
Mean±SD	76.4±5.20	76.5±3.70	75.1±3.5	75.6±3.34		
Median	77.0	76.60	75.05	74.33		
P		0.836		0.950		
Peak air pressure (cmH$_2$O)						
Min.–max.	7.7–19.9	7.2–19.7	5.81–18.75	5.1–18.4	0.001***	0.001***
Mean±SD	11.69±3.89	12.9±3.92	9.85±3.56	10.8±3.6		
Median	11.07	13.57	9.74	10.75		
P		0.351		0.468		
Mean air pressure (cmH$_2$O)						
Min.–max.	2.15–16.9	1.26–11.1	1.88–6.93	1.02–5.41	0.001***	0.001***
Mean±SD	5.3±3.56	4.51±2.4	3.06±1.37	2.37±1.10		
Median	4.16	4.08	2.72	2.14		
P		0.481		0.085		
Mean power (W)						
Min.–max.	1.57–14.35	3.24–9.77	0.73–9.17	0.73–5.42	0.001***	0.001***
Mean±SD	6.42±3.0	6.79±2.42	2.73±2.19	2.28±1.42		
Median	5.79	6.35	2.43	2.11		
P		0.633		0.648		
Mean efficiency (ppm)						
Min.–max.	5.87–45.54	7.52–22.3	8.57–102.2	13.9–97.1	0.001***	0.001***
Mean±SD	14.9±9.30	12.8±5.01	40.9±25.1	47.6±28.0		
Median	13.32	11.52	29.72	34.72		
P		0.604		0.663		

(Continued)

Table 5 (*Continued*)

	Pretherapy		Post-therapy		P_1	P_2
	CVT	TESVT	CVT	TESVT		
Mean resistance (N s/ms)						
Min.–max.	3.47–32.0	1.55–28.3	5.12–38.2	4.98–40.1	0.003**	0.001***
Mean±SD	10.33±6.79	8.97±6.21	13.4±7.5	14.1±8.0		
Median	8.62	8.34	12.55	13.33		
P		0.481		0.756		

CVT, conventional voice therapy; min., minimum; max., maximum; MPT, maximum phonation time; PQ, phonatory quotient; SPL, sound pressure level; TESVT, transcutaneous electrical stimulation-supported voice therapy. P, P value for the Mann–Whitney test comparing between the two studied groups. P_1, P value for the Wilcoxon signed-ranks test for comparing between pretherapy and post-therapy values in the VT group. P_2, P value for the Wilcoxon signed-ranks test for comparing between pretherapy and post-therapy values in the EVT group. **Statistically significant at $P \leq 0.01$. ***Statistically significant at $P \leq 0.001$.

Table 6 Pretherapy and post-therapy electroglottography of both studied groups

	Pretherapy		Post-therapy		P_1	P_2
	CVT	TESVT	CVT	TESVT		
Contact quotient						
Min.–max.	20.6–46.6	10.0–44.4	33.5–50.2	46.6–50.7	0.015*	0.001***
Mean±SD	35.8±8.1	34.2±9.2	42.8±4.6	49.0±1.2		
Median	36.7	36.3	43.0	49.4		
P		0.724		<0.001*		
Open quotient						
Min.–max.	53.4–79.4	55.6–90.0	49.8–66.5	49.4–56.4	0.001***	0.001***
Mean±SD	64.2±8.1	65.8±9.2	57.2±4.6	51.4±1.8		
Median	63.3	63.8	57.0	50.9		
P		0.724		<0.001*		
Speed quotient						
Min.–max.	100.3–172.2	104.7–170.3	165.7–212.8	172.5–252.9	0.001***	0.001***
Mean±SD	143.0±22.2	135.2±21.8	187.5±12.2	203.5±20.9		
Median	144.4	126.5	190.7	199.4		
P		0.290		0.024*		
Opening quotient						
Min.–max.	16.3–33.5	15.4–37.1	24.4–42.7	25.0–42.6	0.001***	0.001***
Mean±SD	24.7±4.7	26.5±5.9	42.7±5.4	33.2±5.4		
Median	25.8	26.9	34.3	34.2		
P		0.330		0.724		
Closing quotient						
Min.–max.	6.49–25.91	1.37–35.64	5.98–19.24	7.36–21.23	0.001***	0.002**
Mean±SD	19.43±5.32	19.88±7.85	13.82±3.64	12.77±3.87		
Median	20.92	21.04	14.04	11.94		
P		0.820		0.330		

CVT, conventional voice therapy; min., minimum; max., maximum; TESVT, transcutaneous electrical stimulation-supported voice therapy. P, P value for the Mann–Whitney test comparing between the two studied groups. P_1, P value for the Wilcoxon signed-ranks test for comparing between pretherapy and post-therapy values in the VT group. P_2, P value for the Wilcoxon signed-ranks test for comparing between pretherapy and post-therapy values in the EVT group. *Statistically significant at $P \leq 0.05$. **Statistically significant at $P \leq 0.01$. ***Statistically significant at $P \leq 0.001$.

rates and subglottic pressure values. A significant increase in mean efficiency and resistance was noted, indicating better glottic closure. The MPT increased significantly and the phonation quotient decreased. The MPT is a function of true vocal fold contact and transglottic air pressure during phonation [32]. Therefore, improvement in MPT and phonation quotient may have been due to increased vocal fold contact. Several studies reported an improvement in

MPT and phonation quotient in patients who received either voice therapy alone or TES in conjunction with voice therapy [23,33–35].

A significant improvement was measured after therapy as regards all EGG parameters. Most participants with vocal fold palsy show a delay in achieving maximum vocal fold contact, resulting in prolonged closing phase of the waveform. The opening phase is short in patients

with vocal fold immobility, as the paralyzed vocal fold loses contact with the healthy one very suddenly when the latter moves laterally. The value of contact quotient is small in patients with vocal fold palsy because of the shorter duration of vocal fold contact in the glottal cycle, caused by later closing and earlier opening of the glottis in the cycle. Functional compensation in this study is reflected in the significant decrease in the values of the open quotient and closing quotient, and increase in opening quotient and contact quotient. Significantly greater improvement was noted among patients in group II as regards the parameters of contact ($P<0.001$), open ($P<0.001$), and speed quotients ($P<0.024$). In a relevant study, Schönweiler *et al.* [35] reported a significant improvement in the contact quotient. They postulated that these results suggest a post-therapeutic improvement in glottic closure through better activity of the adduction musculature as well as a reinforced tension of the thyroarytenoid and/or cricothyroid muscle [35]. However, some authors have shown that TES to the anterior neck stimulates the extrinsic muscles of the larynx only, which would not affect true vocal fold closure. These authors advocate that intrinsic muscles are too distal to be stimulated with TES at normal current and voltage levels [7,36,37].

Conclusion

Transcutaneous electrical stimulation-supported voice therapy is as effective as CVT in improving voice parameters in cases of unilateral vocal fold immobility. We hereby recommend that, in the absence of aspiration and dysphagia, conservative intervention in patients with vocal fold immobility may be recommended and included. Further research is warranted with a larger number of patients to assess the efficacy of transcutaneous electrical stimulation-supported voice therapy in cases of vocal fold immobility and determine selective criteria for this TESVT approach.

Financial support and sponsorship
Nil.

Conflicts of interest
There are no conflicts of interest.

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