Neuromuscular Electrical Stimulation of the Cricothyroid Muscle in Patients With Suspected Superior Laryngeal Nerve Weakness

***,†Marco Guzman, *,‡Adam Rubin, §Paul Cox, ||Fernando Landini, and *,¶Cristina Jackson-Menaldi,** **§St. Clair Shores, ‡Ann Arbor, ¶Detroit, Michigan, and †Santiago, Chile, and ||Buenos Aires, Argentina*

Summary: In this retrospective case study, we report the apparent clinical effectiveness of neuromuscular electrical stimulation (NMES) in combination with voice therapy (VT) for rehabilitating dysphonia secondary to suspected superior laryngeal nerve (SLN) weakness in two female patients. Both patients failed or plateaued with traditional VT but had significant improvement with the addition of NMES of the cricothyroid muscle and SLN using a VitalStim unit. Stimulation was provided simultaneously with voice exercises based on musical phonatory tasks. Both acoustic analysis and endoscopic evaluation demonstrated important improvements after treatment. In the first patient, the major change was obtained within the *primo passaggio* region; specifically, a decrease in voice breaks was demonstrated. In the second patient, an improvement in voice quality (less breathiness) and vocal range were the most important findings. Additionally, each patient reported a significant improvement in their voice complaints. Neuromuscular laryngeal electrical stimulation in combination with vocal exercises might be a useful tool to improve voice quality in patients with SLN injury.

Key Words: Neuromuscular electrical stimulation–Surface electrical stimulation–Superior laryngeal nerve–Cricothyroid muscle–Vocal folds paresis–Voice therapy.

INTRODUCTION

The application of electrical current within a muscle, referred to as neuromuscular electrical stimulation (NMES), will elicit muscle contraction by depolarization of the nerve fibers within the treated region.[1] NMES is a well-known modality in the field of orthopedics and physical medicine.[2] Its aim was threefold: to prevent atrophy of the paretic muscle, speed up the regeneration process, and prevent fibrillation. NMES can induce recovery even in long-term–denervated human muscles.[3] NMES has been widely used for speech-language pathologists in patients diagnosed with dysphagia through surface electrical stimulation.[4–12]

Surface electrical stimulation may help both muscle contraction and sensory input to the central nervous system (CNS).[4,11] Low current levels may activate sensory nerve endings in the surface layers providing sensory feedback to the CNS. When the surface electrical stimulation is applied with higher current levels, it may produce muscle contraction.[13] These effects are commonly accomplished in surface muscles. Deeper muscles are much less likely to be activated by surface stimulation.[14]

The use of NMES for patients with voice disorders has been proposed through surface electrical stimulation.[15,16] Some clinicians and scientists suggest that combining vocal exercises with adjunctive NMES may enhance the positive effects of voice therapy (VT). The combined approach of physical therapy and NMES has been reported to enhance treatment outcomes in sports medicine[17,18] and in stroke rehabilitation[19] but, until recently, had not been tested in rehabilitation of any pathologic laryngeal condition. Schleier et al compared the effects of NMES plus traditional VT versus VT alone in patients with muscle tension dysphonia. They found that the combination of NMES plus VT is better than VT alone.[20] Kruse[21] recommended that NMES should be carried out together with a special voice exercise treatment called functional voice training but did not present data to support this view. The concept of the "neuro-muscular electrophonatory stimulation was later introduced," where the patient performs voice exercises together with single stimulation pulses.[22]

Most applications of neuromuscular stimulation in the larynx have been aimed at reanimating paralyzed muscle.[23–26] Ptok and Starck[27] in a study with 90 patients diagnosed with unilateral vocal fold paralysis compared the outcome of traditional voice exercise treatment with electrical stimulation–supported voice exercise. In the group with NMES, irregularity decreased significantly more than in the traditional VT group after a 3-month therapy period. Maximum phonation time increased similarly in both groups. This study indicates that NMES may be a useful adjunct to traditional VT for patients with unilateral vocal fold paralysis.

LaGorio et al[28] investigated the clinical effectiveness and safety of a novel behavioral VT program combining structured vocal exercise with adjunctive NMES for rehabilitating chronic dysphonia secondary to vocal fold bowing. Results demonstrated that a standardized VT protocol (based on exercise principles and using adjunctive NMES) increased maximum phonation time and glottal closure and decreased supraglottic compression. In addition, patients had significant improvement

Accepted for publication September 9, 2013.
From the *Lakeshore Professional Voice Center, Lakeshore Ear, Nose and Throat Center, St. Clair Shores, Michigan; †School of Communication Sciences, University of Chile, Santiago, Chile; ‡Department of Otolaryngology-HNS, University of Michigan Medical Center, Ann Arbor, Michigan; §Lakeshore Communication Disorders Center, Inc, St. Clair Shores, Michigan; ||Servicio de Otorrinolaringología del Hospital J. M. Ramos Mejía, Universidad de Buenos Aires, Buenos Aires, Argentina; and the ¶Department of Otolaryngology, School of Medicine, Wayne State University, Detroit, Michigan.
Address correspondence and reprint requests to Cristina Jackson-Menaldi, 21000 E. Twelve Mile Road, Suite 111, St. Clair Shores, MI 48081. E-mail: jmenaldi@wayne.edu
Journal of Voice, Vol. 28, No. 2, pp. 216-225
0892-1997/$36.00

http://dx.doi.org/10.1016/j.jvoice.2013.09.003

in the voice handicap index. Authors also suggested that the application of NMES to the anterior neck recruited intrinsic laryngeal muscle fibers, specifically the cricothyroid muscle, thus contributing to increased vocal fold tension and improved glottal closure. Other studies have failed to demonstrate intrinsic laryngeal muscle activation and improvement in vocal fold closure.[14,29,30] Moreover, several studies have investigated the effects of NMES in patients with normal voice. Effects on various objective measures were variable. No consistent pattern was identified.[31,32]

Injury to the superior laryngeal nerve (SLN) can result in dysphonia, and in particular, loss of vocal range. It can be a particularly difficult problem to address either with VT or surgical intervention. The purpose of this retrospective study was to demonstrate the clinical effectiveness of NMES in combination with traditional VT for rehabilitating dysphonia secondary to suspected SLN weakness in two female subjects. We hypothesize that adjunctive VT using NMES could have a potential role in rehabilitating voices in patients with suspected SLN paresis.

METHODS

Case report 1

A 48-year-old music teacher and classically trained soprano presented with a 2-year history of dysphonia after an upper respiratory infection. Her main complaint was a large break in her *primo passaggio* (area of the pitch voice range around 350 Hz, where modal register may shift to a higher register) with significant diplophonia, as well as breathiness in her upper range. She had been evaluated by another laryngologist initially and treated with aggressive reflux management and VT with no improvement over a 2-year period. Her complaints were consistent with perceptual evaluation. She had a dramatic voice break at G#4-A4 (415–440 Hz) (*primo passaggio* region), with the onset of severe diplophonia.

Dynamic assessment of voice and videostroboscopy demonstrated intermittent aperiodicity within the *primo passaggio*, consistent with subjective diplophonia heard within the voice. The laryngologist (A.R.) was suspicious of either a type III sulcus or subtle SLN paresis. Laryngeal electromyography (EMG) was obtained and found to be normal. Videostroboscopy examination also showed intermittent incomplete glottic closure in the midmembranous portion. Amplitude, mucosa wave, and amplitude symmetry were judged to be within normal limits.

She was treated with proton pump inhibitor and traditional VT (VT without NMES). The patient reported slight improvement (less breathy voice quality) after nine sessions of traditional VT, but her voice still showed significant breaks in the *passaggio* region, diplophonia, and breathy upper range. Repeat videostroboscopy showed no significant changes.

The decision was made to proceed to the operating room for a microdirect laryngoscopy for further diagnostic evaluation and potential treatment. No sulcus or significant scarring was identified. Injection laryngoplasty with Cymetra (allergen) (LifeCell Corp., Branchburg, NJ) was performed. The patient felt some improvement, but it was short-lived. Another trial injection laryngoplasty was performed several months later with Radiesse Voice Gel (Merz Aesthetics, Franksville, WI). Again, there was some modest improvement, which waned with time and the diplophonia worsened. After this medical procedure, the patient was treated with traditional VT. Some improvements were observed, but there was still a break in her *passaggio* area. At this point, we discussed several options, including thyroplasty or a trial of NMES. The later was finally performed.

Case report 2

A 63-year-old amateur soprano presented with dysphonia after 10 months of thyroid surgery for multinodular goiter. She complained of decreased vocal range and increased vocal fatigue. Perceptually, she had breathy dysphonia with severely restricted pitch range and low-speaking pitch.

Dynamic voice evaluation and videostroboscopy demonstrated severely decreased longitudinal tension bilaterally with glissando task. Abduction and adduction of the vocal folds appeared normal, but the patient still had incomplete closure in the midmembranous portion of the glottis. Amplitude, mucosal wave, vibratory behavior, and periodicity were all judged to be within normal limits. A diagnosis of bilateral superior laryngeal paralysis (or severe paresis) was made. VT was recommended.

The patient reported some improvement in her speaking voice after five sessions of traditional VT but no significant improvement in vocal range. Voice quality continued to be breathy. Videostroboscopy showed some improvement in glottic closure but no significant improvement in longitudinal tension. The patient's clinical improvement plateaued.

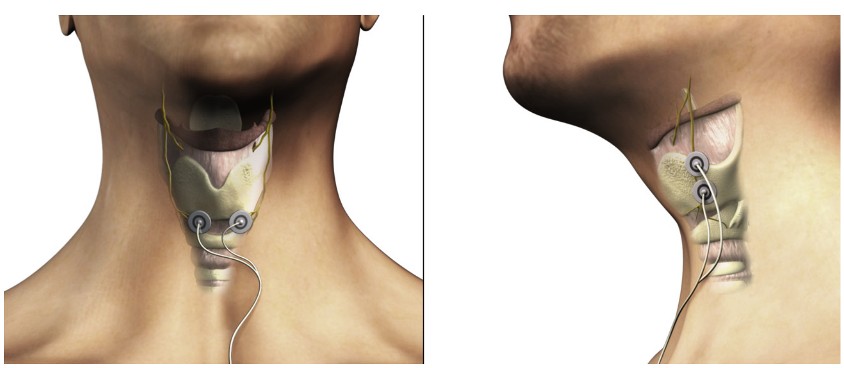

FIGURE 1. Electrodes placement during NMES of the cricothyroid muscle and SLN.

TABLE 1.
Results From the Acoustic Analysis Before and After NMES Therapy for Case 1

Acoustic Parameter	Before Treatment	After Treatment
SFF (Hz)	208	222
SFF range (Hz)	25.6 ST (73–320)	22.4 ST (103–375)
SPI	10.19	4.87
NHR	0.11	0.12
Jitter (%)	0.67	0.5
Shimmer (%)	2.24	3.57
vAm (%)	18.32	11.32
vF0 (%)	1.06	1.15
vAm at G4 (%)	23.88	8.98
vF0 at G4 (%)	3.64	0.64
Cepstral peak (dB)	50	49
SPR (dB)	20.7	20.2
Glissando range (Hz)	31.3 ST (167–1020)	35.6 ST (161–1260)

Abbreviation: ST, semitone.

Ten months after thyroid surgery, the patient still had no improvement in vocal range. NMES of the cricothyroid muscle was added to her therapy. After only four sessions, the patient demonstrated significant improvement. A total of eight sessions were provided.

Informed consent

Because the present work is a retrospective study, no informed consent was obtained from participants, and no approval by an institutional committee for human subject's research was needed.

NMES and VT

NMES using a VitalStim unit (VitalStim, St. Paul, MN) delivers a current between two electrodes through the tissue underneath. The current is delivered in a biphasic pulse in one direction, followed by a brief pause, and then a return in the opposite direction (over the span of 700 microseconds). The VitalStim unit has a preset frequency of 80 Hz.

In our two patients, surface electrodes were placed in two different places: (1) first, in a horizontal configuration along the cricothyroid space and then (2) in a vertical configuration along the posterior part of the thyroid notch (Figure 1). The amplitude or intensity of stimulation was adjusted based on the patient's sensations. At low intensity, the patient feels some tingling and vibration. Intensity is increased until a grabbing or squeezing sensation is felt. The intensity was maintained at this level and then the voice training was initiated. The higher the amplitude, the deeper the current penetration. The intensity of stimulation was also increased as treatment progressed in subsequent sessions. We used a maximum of 13 and 12 mV for the first case and second case, respectively. The maximum that VitalStim allowed is 25 mV.

The voice exercises using during NMES consisted of a sequence of eight different musical phonatory tasks:

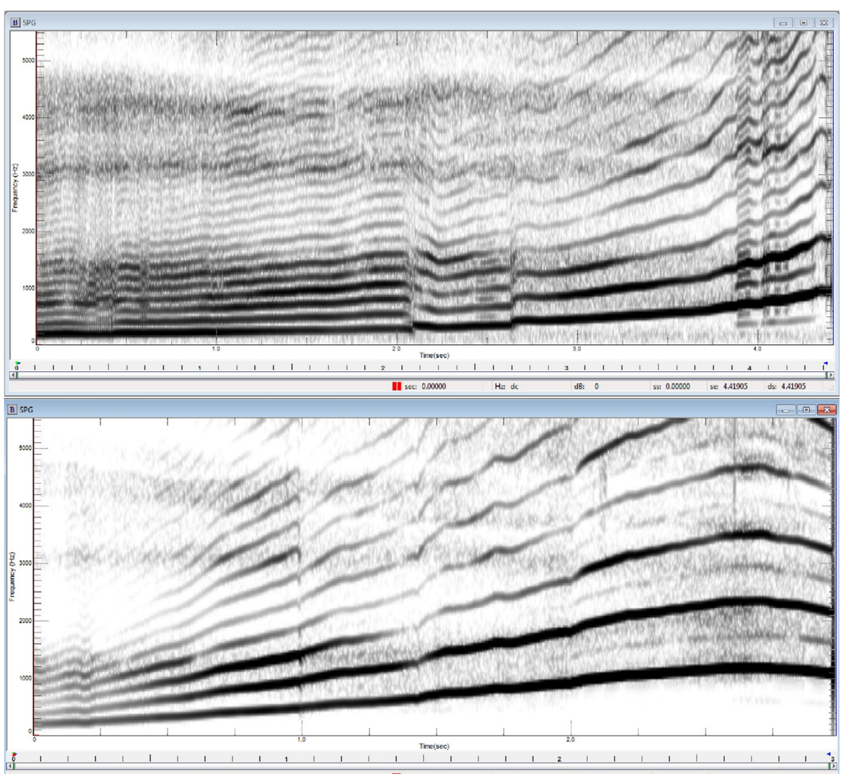

FIGURE 2. Spectrogram during glissando task showing the voice break before treatment (top) and after treatment (bottom) without voice break.

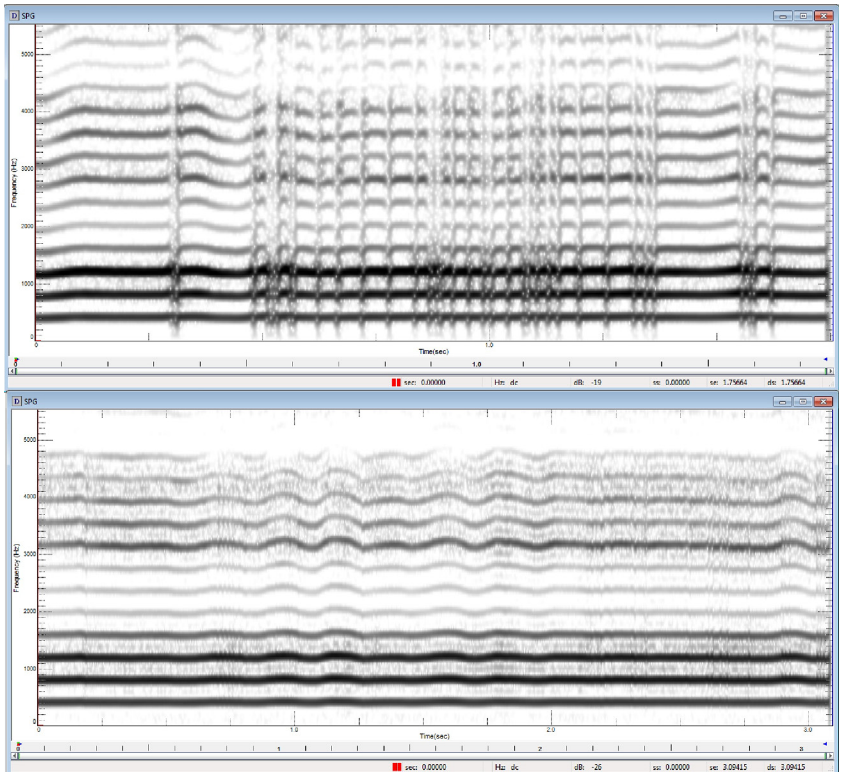

FIGURE 3. Spectrogram during sustained vowel /a/ at G#4 (415 Hz) before voice treatment showing consecutive voice breaks (top) and after treatment (bottom) without voice breaks.

1) Production of sustained different pitches with “hee” starting two tones before the problem region and moving up and down by semitones. Voiceless consonant /h/ was used throughout the exercises to avoid hard glottal attack. Patients also squeezed a ball during exercises to divert tension.
2) Production of intervals of minor seconds (half a tone) with “hee” starting two tones before the problem and moving up and down by semitones. Breath support and voice placement were required during exercising.
3) Production of intervals of major seconds (one tone) with “hee” starting two tones before the problem and moving up and down by semitones.
4) Production of intervals of thirds and fifths with “hee” starting two tones before the problem and moving up and down by semitones.
5) Production of tasks 1–4 using the sequence “mieaou” instead of “hee,” that is, phonation with sustained pitches, intervals of minor seconds, major seconds, thirds, and fifths were used during the production of “mieaou.”
6) Ascending glissando from the lowest to the highest potential frequency and then a descending glissando from the highest to the lowest possible pitch.
7) Production of staccato (/hee/) with intervals of thirds, from comfortable pitch to the highest potential frequency.
8) Singing “Happy Birthday” from the tonality C major to the highest tonality that the patient was able to produce well.
9) Singing any song or aria known by the patient.

The upper pitch limit of all these phonatory tasks was the pitch where the patients were able to do it in tune and without excessive muscle tension. Phonatory tasks were performed with a comfortable loudness level. Vocal exercises plus NMES were performed for 45 minutes, so participants were able to perform each phonatory exercise several times during the treatment session. Patients were allowed to breathe freely and drink water whenever they needed. After each session, laryngeal and neck massage were performed. Patients were also asked to practice the same sequence at home twice a day. They were instructed to use a keyboard or a recording with the same frequencies (tones) that were used in every session of VT.

Acoustic analysis

To assess the changes after NMES with VitalStim, acoustic analysis was carried out. A *Kay Computerized Speech Laboratory* (*CSL*) and *Multidimensional Voice Profile* software (KayPENTAX, Lincoln Park, NJ) were used. Voice samples pre- and posttreatment were measured at a constant microphone-to mouth distance of 10 cm. using a condenser microphone (AKG-Perception-120; AKG Acoustics, Vienna, Austria) connected to the DAT recorder (Marantz PMD 671; Marantz, Mahwah, NJ) in IAC sound suite. Samples were recorded digitally at a sampling rate of 44.1 kHz with 16 bits/sample quantization.

During recording, the patients were asked to produce a sustained vowel/a/, an ascending glissando, to read the rainbow

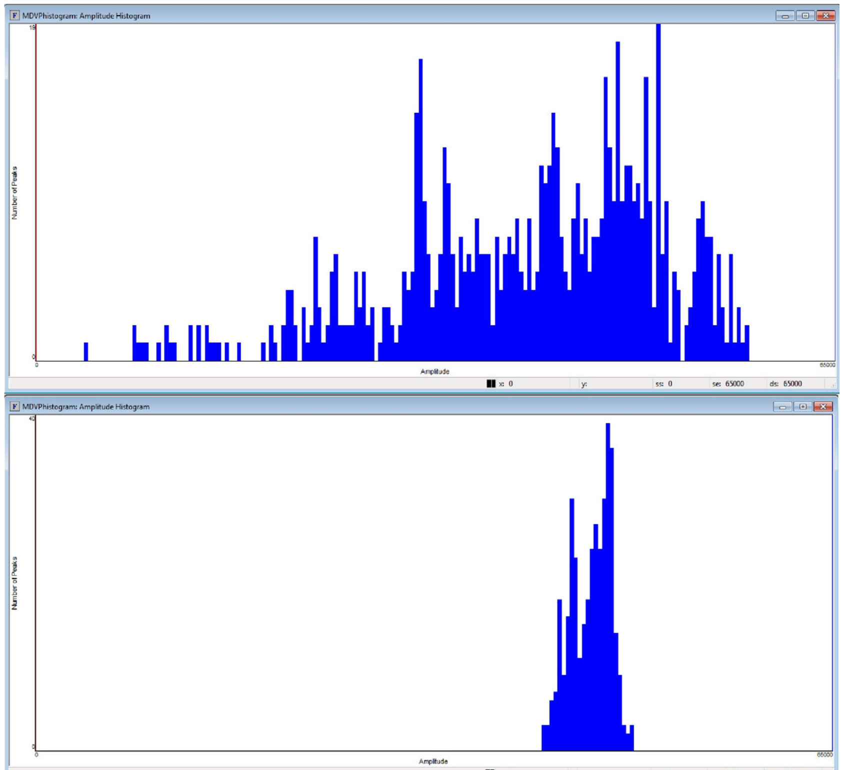

FIGURE 4. Histogram of amplitude before voice treatment (top) showing an important variability and histogram after treatment (bottom) showing a decrease in the amplitude variability.

passage and to sing the song Happy Birthday. An area of at least 3 seconds was selected from the middle part of the speaking vowel /a/ samples to perform the multidimensional analysis of voice. Analyzed parameters included soft phonation index (SPI), noise-to-harmonic ratio (NHR), jitter, shimmer, peak-to-peak amplitude variation (vAm), and fundamental frequency variation (vF0). For our first patient, vAm and vF0 were also assessed during a sustained vowel at G#4-A4 (415–440 Hz). Cepstrum analysis was also performed in the sustained vowel /a/. Because cepstrum peak is a short-term measurement and it is obtained in a specific point of the voice waveform, six different points in middle section of the vowel /a/ waveform were taken and averaged for every sample pre- and posttherapy. The first 60 seconds of the rainbow passage were analyzed with pitch contour protocol to obtain the mean and the range of speaking fundamental frequency (SFF). No vocal fry segments were included in SFF measurements. The song Happy Birthday was analyzed with long-term average spectrum (LTAS). The singing power ratio measurement (the difference of energy between the highest peak around 0–2 kHz and the highest peak around 2–4 kHz) [33] was assessed. The rationale to include the mentioned diverse acoustic measures is that to analyze all possible voice features, it is necessary to take into account short- and long-term variation of fundamental frequency (F_0) and amplitude, glottal noise, spectra tilt, running speech, and singing.

Glissando task was analyzed with the pitch contour protocol of *CSL*. Narrow band spectrogram (1024 points, Hanning window and no pre-emphasis) was also used during glissando and sustained vowel /a/ at G#4 (415 Hz) to observe voice breaks in our first patient.

RESULTS

Case 1

Table 1 summarizes the results from acoustic analysis before and after 17 sessions with NMES. The patient showed a significant improvement in her upper voice range quality and strength of her singing voice. Diplophonia disappeared completely as well as the breathiness in the upper range. Voice break in the *passaggio* region was eliminated during glissando task (Figure 2). Elimination of vocal breaks (voice instability) during sustained vowel at G4 (*primo passaggio*) is shown in Figure 3. An important decrease in the variability of F_0 and amplitude within the *passaggio* after NMES was also observed through histograms (Figures 4 and 5) and through contours of F_0 and amplitude (Figure 6). Videostroboscopy procedure showed a more periodic vocal fold vibration compared with initial assessment.

Case 2

Results from the acoustic analysis before and after eight sessions with NMES are summarized in Table 2. A significant improvement was demonstrated in her upper voice range and strength of her singing voice. Perceptually, the patient's voice was judged as more resonant in the entire range. An increase in the mean and range of the SFF can also be observed. Furthermore, a decreased perturbation and glottal noise parameters

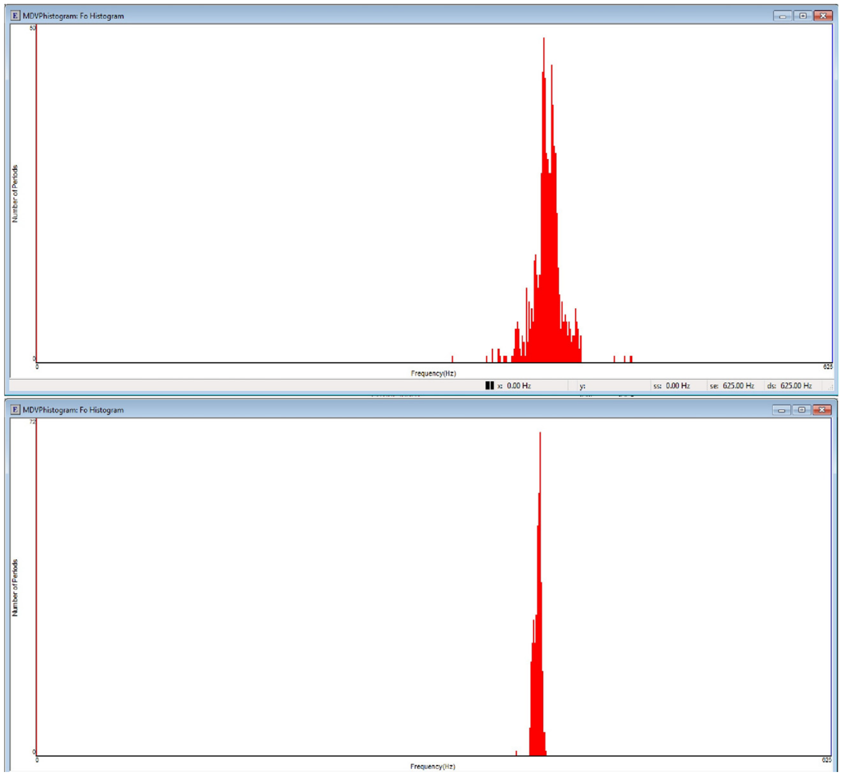

FIGURE 5. Histogram of F_0 before voice treatment (top) showing an important variability and histogram after treatment (bottom) showing a decrease in the vF0.

was demonstrated after treatment. Glissando task also revealed an improvement for clarity. Through singing power ratio (SPR) in the LTAS analysis, a less steep spectral slope was observed (Figure 7). In addition, a stronger cepstral peak was obtained after treatment (Figure 8). Videostroboscopy examination revealed a complete glottal closure after treatment.

DISCUSSION

The results of the present case study have revealed several changes in voice production and voice quality parameters after VT including NMES and physiological vocal exercises. In the first patient, the major change was obtained within the *primo passaggio* region, whereas in the second patient, an improvement in voice quality and vocal range were the most important findings.

Case 1

Our first patient was a challenging case. First, she was vocally treated for 2 years without any improvement before initiate NMES. Second, although the voice difficulties suggested a SLN injury, the EMG did not demonstrate it. The decision to treat her using NMES was based on the fact that despite traditional VT and laryngeal injection produced an improvement in the voice quality, the voice remained with a severe voice break and diplophonia within the *primo passaggio* at G#4-A4 (415–440 Hz), which was affecting significantly her job as a music teacher and personal life. It is important to highlight that the voice exercises used simultaneously to NMES aimed to physiologically improve vocal function by stretching and contacting the vocal folds musculature through ascending and descending musical intervals and glissandos. Moreover, forward voice placement was attempted by using anterior vowels during vocalizations. The forward placement probably helped to reach an adequate glottal configuration toward a more resonant voice quality. A physiological VT approach was used because the purposes of the VT were not only to eliminate the *passaggio* problem but also to balance the three subsystems involved in voice production.

Both vAm and vF0 clearly decreased after NMES in the *passaggio* region (Table 1 and Figure 6). These acoustic parameters are related to the phonatory stability during a sustained vowel production. According to the manufacturer (KayPENTAX), vAm and vF0 indexes reflect a short- and long-term variation of amplitude and F_0, respectively. Moreover, both histograms of F_0 and amplitude (Figures 4 and 5) demonstrated an increment in the stability of the phonatory system at G4 (392 Hz) after VT. These acoustic findings are concordant to the videolaryngoscopy observations. Initial videostroboscopy showed bilateral irregular periodicity in the *passaggio* region, which remained even after trial injection laryngoplasties. After VT with NMES, the periodicity improved significantly. Regarding vocal fold periodicity, Ptok and Starck[27] in a study with patients diagnosed with unilateral vocal fold paralysis compared the outcome of traditional voice exercise treatment with electrical stimulation–supported voice exercise. The author reported that in the group with NMES, irregularity decreased significantly more than the traditional VT group.

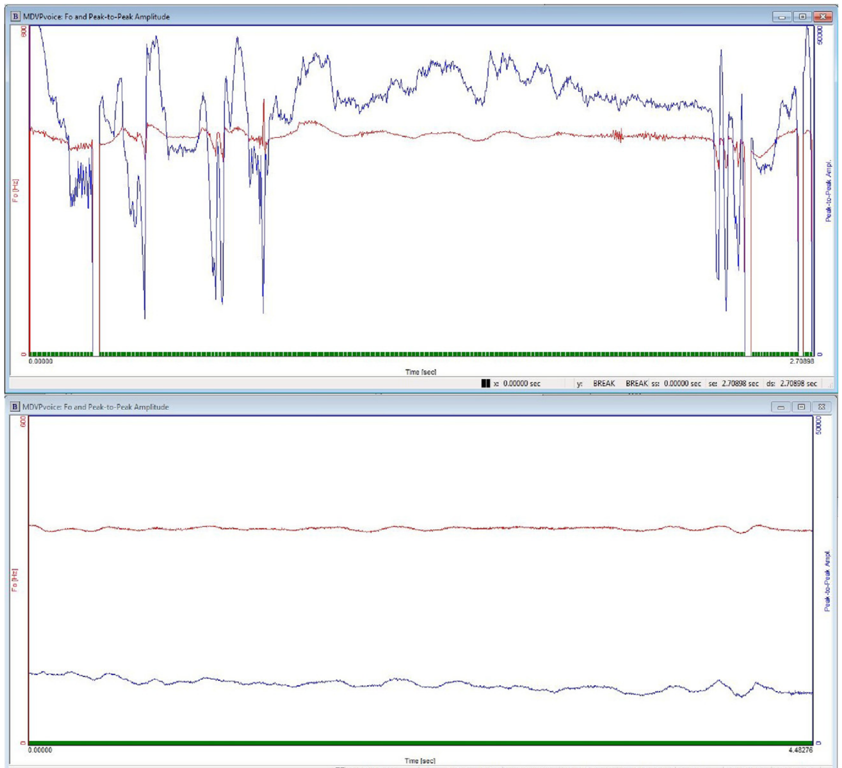

FIGURE 6. Pitch and amplitude contours at G#4 (415 Hz, *primo passaggio*) before voice treatment (top) showing an important instability and contours after treatment (bottom) showing a decrease in the pitch and amplitude instability.

In addition, the patient referred during the initial assessment that her upper voice range was somewhat breathy. Despite NHR remained without change between pre- and post-NMES, the voice quality demonstrated an important perceptual improvement. On the other hand, in the pretreatment evaluation, glissando task revealed a range from 167 to 1020 Hz (36 semitones), which is practically the same as the posttreatment assessment, 161–1260 Hz (39 semitones). Possibly, this parameter did not show an important change after NMES because it was always within normal range for a soprano vocal classification. Furthermore, according to the initial voice assessment, the patient's speaking voice was not adversely affected by her underlying pathology. There were no major changes in perturbation measurements, NHR, cepstral, and LTAS measurements when comparing pre- and post-NMES treatment samples.

TABLE 2.
Results From the Acoustic Analysis Before and After NMES Therapy for Case 2

Acoustic Parameter	Before Treatment	After Treatment
SFF (Hz)	127	163
SFF range (Hz)	13.78 ST (88–195)	22.4 ST (103–375)
SPI	20.11	9.46
NHR	0.16	0.11
Jitter (%)	0.66	0.42
Shimmer (%)	6.52	2.32
vAm (%)	14.15	8.7
vF0 (%)	2.57	1.09
Cepstral peak (dB)	21	62
SPR (dB)	30.2	17.8
Glissando range (Hz)	10.5 ST (108–198)	21.6 ST (120–419)

Abbreviation: ST, semitone.

Case 2

Contrary to our first case, the decision to use NMES in this patient was done a few sessions after initiation of traditional VT. This case was a 63-year-old amateur soprano and clerical

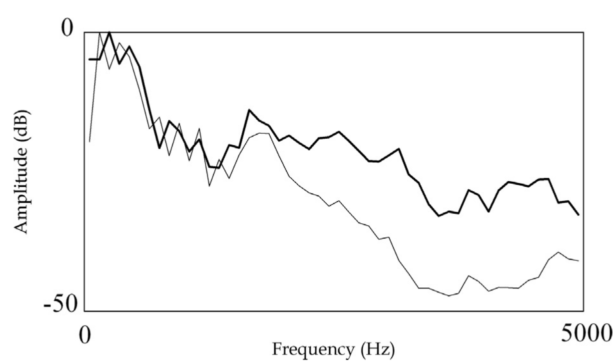

FIGURE 7. LTAS analysis during singing voice before voice treatment (thin line) showing a steeper spectral slope compared with the spectrum after treatment (thick line).

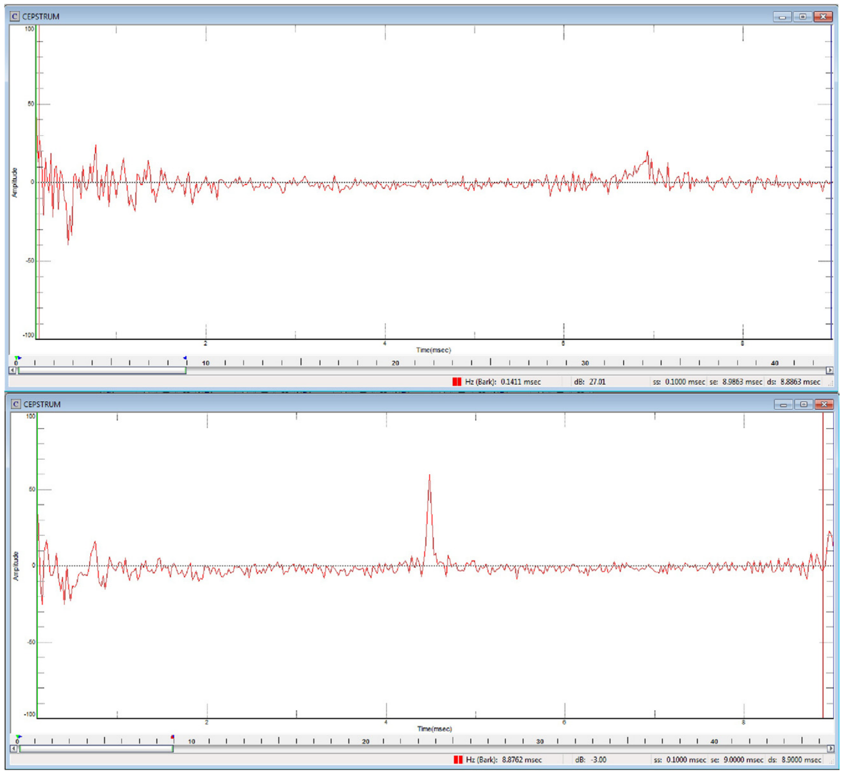

FIGURE 8. Cepstral peak obtained during sustained vowel at SFF before voice treatment (top) and after treatment (bottom). The increased cepstral peak after NMES indicates a more stable voice quality, more harmonic energy, and more periodic signal.

worker who suffered both speaking and singing voice problems after thyroid surgery. Symptoms appeared to be a consequence of SLN injury (diagnosis was made by a fellowship-trained laryngologist). Perceptually, she had breathy dysphonia with severely restricted pitch range. Similar to the patient in case 1, the same physiological vocal exercises were used to strengthen the vocal folds musculature. Ascending-descending glissandos and musical intervals aimed to recover vocal fold elongation. The purpose of forward sounds used in the exercise sequence was to promote a proper vocal fold adduction. The patient was asked to produce resonant voice quality (with face tissue vibration without vocal effort) during exercises to help the reduction of the glottal chink and hence to reduce breathiness.

After eight sessions of VT with NMES, the patient reported some improvement in her speaking voice, and perceptually, her voice quality was less breathy. This observation is concordant with the acoustic analysis outcomes. A relevant change was found in both LTAS and cepstrum analysis. The increased cepstral peak after NMES indicates a more stable voice quality, more harmonic energy, and more periodic signal. Cepstrum is defined as a Fourier transformation of a spectrum.[34,35] A strong cepstral peak (high value) is obtained from a voice characterized by a well-defined harmonic structure (normal voice). On the other hand, a breathy and hoarse voice has a poorly defined harmonic structure; hence, the cepstral peak is weak (low value). Previous studies have reported that cepstral peak value is the best predictors of overall dysphonia in comparison with perturbation and noise measures.[36–39] Additionally, cepstrum-related measures have shown strong correlations to dysphonia severity in different voice disorders.[40–44]

A recent study aimed to measure cepstral peak in individuals with unilateral vocal fold paralysis (UVFP), revealed an abnormal reduction of the cepstral peak value in speakers with UVFP relative to the normal controls, as they are characterized by a breathy voice because of inadequate closure of vocal folds.[42] In our patient, the cepstral peak change between pre- and posttreatment showed the most dominant objective acoustic improvement after NMES; thus, it is concordant to previous reports.

The SPR revealed an important decrease after NMES. This parameter has been widely studied in professional singers as an acoustic marker of good voice quality (more resonant voice). This change (decrease of SPR value) suggests a change in the spectral slope declination (ie, less steep slope). The lower value of SPR after treatment represents an increased energy in the higher harmonics of the spectral slope. In other words, there is less difference between the energy of the lower harmonics and energy of the higher harmonics after NMES. Related to this change, it is interesting to observe that the soft phonation index (SPI) shows an important decrease after therapy in this study as well. Despite of SPI being classified as a noise measurement by the manufacturer (KayPENTAX), this parameter could also be considered indirectly as a spectral slope declination feature. This assumption is based on the fact that SPI value is obtained from the ratio between spectral harmonic energy of low frequencies (70–1600 Hz) and spectral harmonic energy of high frequencies (1600–4500 Hz). Therefore, a decreased SPI value means that the energy of high harmonics is increased. In this case report, there is an interesting direct relation between these two measurements, SPR and SPI, both demonstrated a decrease after VT.

In this patient, NMES also seemed to improve glottal closure. This was demonstrated by acoustical analysis as well as videostroboscopy. Concordantly with our findings, LaGorio et al[28] demonstrated that a standardized VT protocol (based on exercise principles and using adjunctive NMES) increased maximum phonation time and glottal closure in patients with dysphonia secondary to vocal fold bowing. Likewise, Ptok et al[27] reported an increase in maximum phonation time after a 3-month therapy with NMES in a group of patient diagnosed with UVFP.

During initial voice evaluation, this patient demonstrated not only a perceptually breathy dysphonia but also a severely restricted pitch range and limited SFF range. Objective analysis during reading tasks revealed a significant increase in SFF range. Because SFF range increased three times after therapy, this is considered a major change, probably due to NMES plus the ascending musical intervals and glissando task used in this patient. In addition, the improvement of glissando task could also be considered as an important change, but it is still reduced comparing with normal range. Eight sessions with NMES were provided to this patient. It is possibly that additional treatment might help more.

There are some limitations to this report. In the first case, laryngeal EMG was normal. Therefore, there was no objective evidence of SLN injury. However, her clinical presentation and lack of other structural pathology makes us highly suspicious that her problem was related to the SLN. Her improvement with stimulation of the cricothyroid muscle after several years of no improvement with traditional VT with reputable therapists also supports this notion.

In case #2, we did not obtain laryngeal EMG because the endoscopic evaluation was so clearly supportive of the diagnosis. There was essentially no significant glissando capability. Furthermore, one could argue that her improvement may have been due to the natural history of nerve recovery after a nontransection injury as it improved within a year time. However, the patient had no improvement 10 months after the injury and improved only after eight sessions of therapy with NMES. This has at least suggested the NMES helped. Furthermore, the patient's voice has not recovered to preinjury quality. If this was just a traction injury, one would expect it likely would have.

CONCLUSION

Neuromuscular laryngeal electrical stimulation in combination with traditional vocal exercises may be useful to improve both speaking and singing voice quality in patients with SLN weakness. Further prospective case-controlled studies may be useful to conclusively prove its effectiveness.

REFERENCES

1. Bidus K, Thomas G, Ludlow C. Effects of adductor muscle stimulation on speech in abductor spasmodic dysphonia. *Laryngoscope*. 2000;110:1943–1949.
2. Low J, Reed A. *Electrotherapy Explained*. 3rd ed. Oxford, UK: Butterworth-Heinemann; 2000.
3. Kern H, Salmons S, Mayr W, Rossini K, Carraro U. Recovery of long-term denervated human muscles induced by electrical stimulation. *Muscle Nerve*. 2005;31:98–101.
4. Leelamanit V, Limsakul C, Geater A. Synchronized electrical stimulation in treating pharyngeal dysphagia. *Laryngoscope*. 2002;112:2204–2210.
5. Shaw G, Sechtem P, Searl J, Keller K, Rawi T, Dowdy E. Transcutaneous neuromuscular electrical stimulation (VitalStim) curative therapy for severe dysphagia: myth or reality? *Ann Oto Rhinol Laryn*. 2007;116:36–44.
6. Carnaby-Mann GD, Crary MA. Examining the evidence on neuromuscular electrical stimulation for swallowing: a meta-analysis. *Arch Otolaryngol Head Neck Surg*. 2007;133:564–571.
7. Crary M, Carnaby-Mann G, Faunce A. Electrical stimulation therapy for dysphagia: descriptive results of two surveys. *Dysphagia*. 2007;22:165–173.
8. Bulow M, Speyer R, Baijens L, Woisard V, Ekberg O. Neuromuscular electrical stimulation (NMES) in stroke patients with oral and pharyngeal dysfunction. *Dysphagia*. 2008;23:302–309.
9. Camaby-Mann G, Crary M. Adjunctive neuromuscular electrical stimulation for treatment-refractory dysphagia. *Ann Oto Rhinol Laryn*. 2008;117:279–287.
10. Bogaardt H, Van Dam D, Wever N, Bruggeman C, Koops J, Fokkens W. Use of neuromuscular electrostimulation in the treatment of dysphagia in patients with multiple sclerosis. *Ann Oto Rhinol Laryn*. 2009;8:241–246.
11. Park J, Oh J, Lee H, Park S, Yoon T, Kwon B. Effortful swallowing training coupled with electrical stimulation leads to an increase in hyoid elevation during swallowing. *Dysphagia*. 2009;24:296–301.
12. Ryu J, Kang J, Park J, et al. The effect of electrical stimulation therapy on dysphagia following treatment for head and neck cancer. *Oral Oncol*. 2009;45:665–668.
13. Loeb GE, Gans C. *Electromyography for Experimentalists*. Chicago, IL: The University of Chicago Press; 1986.
14. Ludlow CL, Humbert I, Saxon K, et al. Effects of surface electrical stimulation both at rest and during swallowing in chronic pharyngeal dysphagia. *Dysphagia*. 2007;22:1–10.
15. Kraus WM, Sanders I, Aviv JE, Biller HF. Laryngeal electrode platform: an indwelling device for mobilizing the vocal cords. *Ann Otol Rhinol Laryngol*. 1987;96:674–679.
16. Sanders I, Aviv J, Kraus WM, Racenstein MM, Biller HF. Transcutaneous electrical stimulation of the recurrent laryngeal nerve in monkeys. *Ann Otol Rhinol Laryngol*. 1987;96:38–42.
17. Maffiuletti NA, Dugnani S, Folz M, Di Pierno EL, Mauro FL. Effect of combined electrostimulation and plyometric training on vertical jump height. *Med Sci Sports Exerc*. 2002;34:1638–1644.
18. Valli P, Boldrini L, Bianchedi D, Brizzi G, Miserocchi G. Effects of low intensity electrical stimulation on quadriceps muscle voluntary maximal strength. *J Sports Med Phys Fitness*. 2002;42:425–430.
19. Chae J, Sheffler L, Knutson J. Neuromuscular electrical stimulation for motor restoration in hemiplegia. *Top Stroke Rehabil*. 2008;15:412–426.
20. Schleier E, Streubel HG. Behandlungsergebnisse nach einer kombinierten Stimm-Reizstromtherapie mit asynchronem Exponentialstrom bei hypofunktionellen Dysphonien und Internusschwachen. *Folia Phoniatric Logo*. 1980;32:70–77.
21. Kruse E. Systematik der konservativen Stimmtherapie aus phoniatrischer Sicht. In: Bohme G, ed. *Sprach-, Sprech-Stimm- und Schluckstörungen, 2nd ed. Vol 2. Therapie*. Stuttgart, Germany: Fischer; 1998.
22. *VitalStim Certification Program Training Manual*. Birmingham, AL: VitalStim; 2004.
23. Sanders I. Electrical stimulation of laryngeal muscle. *Otolaryngol Clin North Am*. 1991;24:1253–1274.
24. Zealear DL, Rainey CL, Jerles ML, Tanabe T, Herzon GD. Technical approach for reanimation of the chronically denervated larynx by means of functional electrical stimulation. *Ann Otol Rhinol Laryngol*. 1994;103:705–712.
25. Sanders I, Rao F, Biller HF. Arytenoid motion evoked by regional electrical stimulation of the canine posterior cricoarytenoid muscle. *Laryngoscope*. 1994;104:456–462.

26. Zealear DL, Rainey CL, Netterville JL, Herzon GD, Ossoff RH. Electrical pacing of the paralyzed human larynx. *Ann Otol Rhinol Laryngol*. 1996; 105:689–693.
27. Ptok M, Starck D. Electrical stimulation-supported voice exercises are superior to voice exercises therapy alone in patients with unilateral recurrent laryngeal nerve paresis: results from a prospective, randomized clinical trial. *Muscle Nerve*. 2008;38:1005–1011.
28. LaGorio L, Carnaby-Mann G, Crary M. Treatment of vocal fold bowing using neuromuscular electrical stimulation. *Arch Otolaryngol Head Surg*. 2010;4:398–403.
29. Humbert IA, Poletto CJ, Saxon KG, et al. The effect of surface electrical stimulation on hyo-laryngeal movement in normal individuals at rest and during swallowing. *J Appl Phys*. 2006;101:1657–1663.
30. Humbert IA, Poletto CJ, Saxon KG, et al. The effect of surface electrical stimulation on vocal fold position. *Laryngoscope*. 2008;118:14–19.
31. Fowler L, Gorham-Rowan M, Hapner E. An exploratory study of voice change associated with healthy speakers following transcutaneous electrical stimulation to laryngeal muscles. *J Voice*. 2011;25:54–61.
32. Gorham-Rowan M, Fowler L, Hapner E. Acoustic analysis of voice change in normal speakers following transcutaneous electrical stimulation to the laryngeal area. *Open Rehabil J*. 2010;3:67–74.
33. Omori K, Kacker A, Carroll L, Riley W, Blaugrund S. Singing power ratio: quantitative evaluation of singing voice quality. *J Voice*. 1996;10:228–235.
34. Hillenbrand J, Cleveland RA, Erickson RL. Acoustic correlates of breathy vocal quality. *J Speech Hear Res*. 1994;37:769–778.
35. Hillenbrand J, Houde RA. Acoustic correlates of breathy vocal quality. *J Speech Hear Res*. 1996;39:311–321.
36. Heman-Ackah YD, Heuer RJ, Michael DD. Cepstral peak prominence: a more reliable measure of dysphonia. *Ann Otol Rhinol Laryngol*. 2003; 112:324–333.
37. Heman-Ackah YD, Michael DD, Goding GS Jr. The relationship between cepstral peak prominence and selected parameters of dysphonia. *J Voice*. 2002;16:20–27.
38. Heman-Ackah YD. Reliability of calculating the cepstral peak without linear regression analysis. *J Voice*. 2004;18:203–208.
39. Zieger K, Schneider C, Gerull G, Mrowinski D. Cepstrum analysis in voice disorders. *Folia Phoniatr Logop*. 1995;47:210–217.
40. Eadie TL, Baylor CR. The effect of perceptual training on inexperienced listeners' judgments of dysphonic voice. *J Voice*. 2006;20:527–544.
41. Awan SN, Roy N. Toward the development of an objective index of dysphonia severity: a four-factor acoustic model. *Clin Linguist Phon*. 2006;20:35–49.
42. Radish Kumar B, Bhat JS, Prasad N. Cepstral analysis of voice in persons with vocal nodules. *J Voice*. 2010;24:651–653.
43. Balasubramanium RK, Bhat JS, Fahim S 3rd, Raju R 3rd. Cepstral analysis of voice in unilateral adductor vocal fold palsy. *J Voice*. 2011;25: 326–329.
44. Lowell SY, Colton RH, Kelley RT, Hahn YC. Spectral- and cepstral-based measures during continuous speech: capacity to distinguish dysphonia and consistency within a speaker. *J Voice*. 2011;25:223–232.