TREATMENT OF VOCAL FOLD BOWING USING NEUROMUSCULAR ELECTRICAL STIMULATION

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Objective: To investigate the clinical effectiveness and safety of a novel behavioral voice therapy program combining structured vocal exercise with adjunctive neuromuscular electrical stimulation for rehabilitating dysphonia secondary to vocal fold bowing.

Design: Prospective interventional clinical case series with a 3-month follow-up.

Setting: Outpatient speech and hearing clinic in an academic medical center.

Patients: Convenience sample of 7 patients diagnosed by an otolaryngologist as having chronic dysphonia for at least 3 months due to bilateral vocal fold bowing.

Intervention: A novel voice therapy program incorporating exercise principles and sustained phonations of increasing length, volume, and pitch paired with concurrent transcutaneous neuromuscular electrical stimulation.

Main Outcome Measures: Change in maximum phonation time, highest attainable pitch, glottal closure, supraglottic compression, and Voice Handicap Index.

Results: Maximum phonation time for /i/ increased significantly (z = -2.201, P < .03), with a modest effect demonstrated (Hedges g, 0.65; 95% confidence interval, -0.56 to 1.75). Voice Handicap Index trended toward significance (z = -1.787, P < .07). Glottal closure during phonation improved, and supraglottic compression decreased. Improvements were maintained or enhanced at the 3-month follow-up. Analysis of highest attainable pitch data was limited owing to aperiodicity in the baseline evaluations.

Conclusions: Behavioral voice therapy with adjunctive neuromuscular electrical stimulation reduced vocal fold bowing, resulting in improved acoustic, laryngeal, and patient-centered outcomes. Maximum phonation time and glottal closure results imply increased vocal fold tension secondary to enhanced thyroarytenoid or cricothyroid muscle function after voice therapy.


VOCAL FOLD BOWING IS A FREQUENT CAUSE OF DYSPHONIA IN OLDER PERSONS, REPORTEDLY AFFECTING 20% TO 29% OF THE GERIATRIC POPULATION.1,2 Furthermore, more than 50% of older persons with dysphonia from bowed vocal folds report significant decline in quality of life.1 However, vocal fold bowing is not limited to older populations. For example, Reulbach et al3 identified previously undiagnosed glottal incompetence from bowed vocal folds in 72% of a cohort of healthy adults 40 years and older. Hanson et al4 identified vocal fold bowing in 94% of patients with Parkinson disease. Mechanisms of vocal fold bowing are presumed but unknown5 and may include intubation-related damage to laryngeal mucosa,6 vocal fold stiffening,7 vocal fold paresis,7 sulcus vocalis,7 or laryngeal atrophy.7,8 Regardless of the cause, treatment of dysphonia due to bowed vocal folds has focused on therapeutic laryngeal injection or thyroplastic medialization.5,10 Evidence supporting the benefit of voice therapy for dysphonia secondary to bowed vocal folds in otherwise healthy adults is limited.11 However, related efforts suggest that laryngeal muscles might be strengthened with voice therapy based on exercise principles. For example, Ramig12 and Smith et al13 reported that resistance exercise targeting vocal intensity and respiratory function decreased glottal incompetence and improved voice quality in patients with bowed vocal folds secondary to Parkinson disease. Recently, we reported that dysphagia therapy with adjunctive transcutaneous neuromuscular electrical stimulation (NMES) reduced vocal fold bowing and improved voice performance in a single patient who had received radiotherapy for head and neck cancer.14 Combining exercise with adjunctive NMES may enhance the positive effects of voice therapy. This combined approach has been reported to enhance treatment outcomes in sports medicine15,16 and in stroke rehabilitation17 but, until recently, had not been tested in rehabilitation of any pathologic laryngeal condition. In 2008, Ptok and Strack18 demonstrated that pairing voice therapy with transcutaneous electrical stimulation decreased vocal fold vibration irregularity in patients with uni-
lateral vocal fold paralysis. Moreover, our aforementioned study of reduced vocal fold bowing with concomitant voice improvement showed enhanced vocal fold tension following pharyngeal and laryngeal exercise combined with transcutaneous NMES. Given these results, we hypothesized that an exercise-based voice therapy program paired with adjunctive transcutaneous NMES may improve vocal and laryngeal function in patients with bowed vocal folds contributing to dysphonia.

Robey described a 5-phase model of clinical research structuring a series of clinical investigations leading to a comprehensive evaluation of any novel intervention. The initial phase in this model is to describe and measure any clinical effect of the intervention. In this regard, a phase 1 study should focus on a specified therapeutic outcome and should delineate how this outcome is to be evaluated. Acceptable research designs to accomplish this goal include case reports, prospective case series, and retrospective studies.

In the present study, we report the results of a prospective case series to evaluate the clinical effectiveness and safety of a novel voice therapy program with adjunctive NMES in the rehabilitation of dysphonia secondary to bowed vocal folds. We specify clinical outcomes used in the assessment of this intervention and describe a consistent course of voice therapy applied to 7 patients having chronic dysphonia secondary to bilateral vocal fold bowing.

METHODS

PATIENTS

Adults having chronic dysphonia for at least 3 months due to bilateral true vocal fold bowing were recruited to participate in the treatment study from June 1, 2007, to May 15, 2008. Patients were referred from local otolaryngologists familiar with the study. Patients with tracheotomy, progressive neurologic disease, history of laryngeal cancer, or other organic, neuromuscular, or functional cause for dysphonia were excluded from this study. Patients with cardiac demand pacemakers were also excluded, as this diagnosis is listed as a caution for electrical stimulation by the Food and Drug Administration. The local institutional review board approved all procedures used in this study, and all enrolled patients signed an approved informed consent form.

BASELINE MEASURES

Before voice therapy, each patient completed baseline acoustic and stroboscopic laryngeal evaluations, pulmonary function testing, and Voice Handicap Index (VHI) questionnaire. These measures served to ensure inclusion criteria, determine initial voice therapy goals, and provide a pretherapy measure on outcome assessments.

ACOUSTIC VOICE EVALUATION

Acoustic voice evaluation was completed using a commercially available system (Computerized Speech Laboratory 4500: KayPentax, Lincoln Park, New Jersey). Signals were captured via a headset-mounted condenser microphone (C420 PP MicroMic III; AKG Acoustics, Vienna, Austria) set at a uniform 1/2-in distance in front of the patient's mouth during all recordings. A real-time pitch program (RTP model 5121, KayPentax) was used to measure maximum phonation time (MPT) and highest attainable pitch (HAP) for sustained /i/ and /a/ as well as loudest volume produced saying “Hey you.” Patients completed 3 trials of each task; the mean performance values were used in the analysis.

STROBOSCOPIC LARYNGEAL EVALUATION

Laryngeal evaluations were completed using a stroboscope (9200C Rhino-Laryngeal Stroboscope, KayPentax) with a flexible endoscope (ENF-P4; Olympus, Tokyo, Japan). These evaluations confirmed the presence of true vocal fold bowing, set the NMES level used in treatment sessions, and described laryngeal configuration during phonation. Laryngeal configuration variables examined were glottal closure and supraglottic compression.

PULMONARY FUNCTION EVALUATION

Pulmonary function evaluation was completed using a handheld spirometer (Discovery; Futuemed America Inc, Granada Hills, California). Patient age, sex, height, and weight were entered into the spirometer for calculation of forced expiratory volume in the first second of expiration (FEV1) and forced vital capacity. Patients were instructed to take a deep breath and to blow out forcefully. Patients completed 3 trials; the mean performance values were used in the analysis. The ratio of FEV1 to forced vital capacity (FEV1%) was calculated for each patient and was used as a control measure in the outcome analysis. This measure provides a clinical means of assessing airflow limitation during expiration, reflecting integrity of the respiratory muscles. Because respiratory muscles are known to adapt to exercise, any statistically significant change in FEV1% following treatment would indicate change in underlying respiratory musculature function. Therefore, this pulmonary measure was incorporated as a control measure in an attempt to separate the effects of laryngeal vs pulmonary changes as a result of voice therapy.

INTERVENTION

The voice therapy protocol consisted of a hierarchy of vocalizations paired with adjunctive transcutaneous NMES. Sessions were 1 hour daily, 5 days per week, for 3 weeks. Patients completed 2 pretherapy accommodation sessions. These accommodation sessions served to familiarize patients with the voice therapy program and performance criteria, answer any questions about NMES, and minimize any anticipatory bias. Patients received 10 and 20 minutes of NMES, respectively, during the first and second accommodation sessions. During the subsequent 13 voice therapy sessions, patients completed a standardized protocol of vocal exercises, while simultaneously receiving 60 minutes of NMES.

Vocal exercises consisted of a progressive 14-step series of pharyngeal activities. The task hierarchy was developed to systematically increase resistance to the weakened vocal folds and to expand the phonatory environment over time. To do this, the exercise concept of 1-repetition maximum (1RM) was adapted to voice. One-repetition maximum describes the maximum load that can be moved 1 time. This value is used to set training intensity levels, with optimal exercise levels for strength training set at 80% of 1RM. To adapt 1RM for this vocal exercise protocol, load was defined as length (MPT), volume, and pitch (HAP) of sustained phonation; 1RM was defined as the highest performance value of 1 of 3 baseline trials of MPT, volume, and HAP. Patients' individual vocal exercise goals were calculated as 60%, 70%, and 80% of baseline 1RM and were used to measure successful performance at each step in the vocal exercise task hierarchy. For example, during step 1, patients were required to produce and sustain a hum for 60% of baseline MPT until performance criteria for successful phonation were achieved. Once achieved, the
length of sustained phonation was increased to 70% and then 80% of baseline MPT. Vocal exercise continued in this fashion, next incorporating /i/ and /a/ then volume, and then HAP so that, as patients progressed in the task hierarchy, they were required to produce and sustain phonations that were incrementally longer, louder, and higher pitched than previous phonations. Following completion of step 6 in the treatment hierarchy, 1RM for MPT was remeasured, and 60%, 70%, and 80% phonation length goals were recalculated. These new MPT goals were used during the remaining steps in the hierarchy. Once patients reached step 12 in the vocal exercise program, target phonations changed from sustained vowels to words, phrases, and conversation.

PERFORMANCE MONITORING

The treating speech-language pathologist (L.A.L.) recorded successful and unsuccessful phonation attempts. Successful phonations involved producing and sustaining a target phonation without hoarseness, breathiness, or pitch breaks for the specified length of time. Each phonation attempt was judged by the clinician and by the patient. Successful productions required agreement between clinician and patient. To advance to higher levels in the voice therapy program, patients were required to phonate with 80% accuracy (8 of 10 attempts) per vocal exercise set and to complete 3 successful consecutive sets per level. Failure on 3 of 5 phonation attempts in any set was considered a failure of that set.

TRANSCUTANEOUS NMES

Neuromuscular electrical stimulation was delivered using a commercially available device (VitalStim NMES; Empi Corporation, St Paul, Minnesota). The unit is a dual-channel bipolar device that supplies rectangular, symmetric, biphasic pulsed current at a preset fixed pulse rate of 80 Hz and pulse duration of 700 microseconds (VitalStim Therapy®). The dual channels allow the user to independently set the stimulation amplitude from 0 to 25 mA (tolerance ±10%). Adult electrodes (VitalStim 50000) are circular, have a 2.1-cm diameter, and provide 3.46-cm² surface area of stimulation via a carbon-silver substrate. One pair of electrodes was placed vertically at the midline immediately above and below the cricothyroid membrane. This electrode pair targeted NMES to the cricothyroid muscles. The other pair of electrodes was placed horizontally, inferior and slightly medial to the posterior horns of the hyoid bone near the presumed location of the superior laryngeal nerves (Figure).

Before applying the electrodes, all men were clean shaved, and all patients' necks were cleaned with an alcohol-based wipe (TENS Clean-Cote Unipatch, MS71000, model UP220; Tyco Healthcare, Wabasha, Wisconsin). Once affixed, the electrodes were taped to the skin (Transpore; 3M, St Paul). Last, during treatment sessions, a 3-in-wide elastic bandage was wrapped around the neck over the electrodes to further assist in maintaining appropriate skin to electrode contact.

IDENTIFICATION OF NMES AMPLITUDE

Treatment NMES level was determined during the baseline stroboscopic laryngeal evaluation. Neuromuscular electrical stimulation was increased from 0 mA in 2-mA increments until improved glottal closure or vibratory pattern was reported by the stroboscopic examiner (M.A.C.). Once an effect on glottal closure was identified, NMES amplitude was decreased systematically by 1 mA until the baseline glottal closure or vibratory pattern was again observed. Next, NMES amplitude was again increased in 0.5-mA increments until improved glottal closure or vibratory pattern was reidentified. This NMES amplitude was subsequently used for all treatment sessions. To minimize examiner (M.A.C.) bias, the examiner remained blinded to NMES amplitude applied during the examination.

OUTCOME BLINDING

Voice therapy sessions were conducted by one experienced speech-language pathologist, who was blinded to the results of all assessments. Only the therapeutic NMES level was available to the treating speech-language pathologist (L.A.L.). Outcome assessors were blinded to the results of the treatment sessions.

TREATMENT OUTCOMES

Primary outcome measures assessed included change in MPT, HAP, VHI, and laryngeal configuration during phonation. A secondary outcome measure was change in pulmonary function, FEV₁%, which was used as a control evaluation of the stability of respiratory support for phonation.

LARYNGEAL CONFIGURATION DURING PHONATION

To rate glottal closure and supraglottic compression, video clips of sustained /i/ were obtained from each patient’s stroboscopic laryngeal examinations at baseline, after voice therapy, and at the 3-month follow-up. Video samples were edited to equal lengths of 3 to 5 seconds, deidentified, arranged into a series of randomized pairs, and presented to raters (G.D.C.-M. and M.A.C.) in a slide format (PowerPoint, Microsoft Office 2003; Microsoft Corp, Redmond, Washington).

Two experienced independent judges rated each pair. Ratings from the more experienced judge (M.A.C.) were used to evaluate change in laryngeal configuration during phonation. Ratings from the second judge (G.D.C.-M.) were used to estimate interrater reliability. Judges viewed the pairs and chose the video from each pair that best demonstrated better glottal closure and less supraglottic compression. Each of these laryngeal configuration outcome variables was rated separately. Judges rated pairs as “no difference” when the pair was perceived to be identical for each outcome measure or “cannot see” if either video of the pair was of too poor quality to rate either of the 2 laryngeal configuration variables. Video pairs were automatically played on a continuous-motion loop. Judges were al-
allowed to stop and start the playback as needed but were not permitted to look back at previously rated pairs.

**STATISTICAL ANALYSIS**

Patient demographics were reviewed using descriptive methods. Because of few patients and skewed distributions, the non-parametric Wilcoxon signed rank test of matched pairs was used to assess pretreatment and posttreatment performance change for the continuous variables. Clinical effect for significant outcomes was estimated using Hedges' $g$ statistic.24 Interrater reliability for both laryngeal configuration variables was calculated using $\kappa$ statistic.25

**RESULTS**

**BASELINE CHARACTERISTICS**

A convenience sample of 7 patients enrolled in the study, 4 men and 3 women, with a mean (SD) age of 66.9 (8.4) years (age range, 58-81 years). All patients demonstrated bilateral vocal fold bowing with adequate laryngeal abduction and adduction. Based on patient history, the presumptive cause of bowed vocal folds was presbyphonia in 5 patients, multiple intubations in 1 patient, and unknown (possibly virus related) in 1 patient.

**FOLLOW-UP EVALUATIONS**

Posttreatment data were completed for 6 of 7 patients. One male patient withdrew after completing the first week of treatment because of complaints of muscle soreness in his right lateral neck over the larynx. Clinical and endoscopic evaluations 3 days after withdrawal from the study were unremarkable, and the patient denied any discomfort at that time. Data from this patient were not included in the results.

**TREATMENT SESSION AND NMES VARIABLES**

The remaining 6 patients completed all 15 sessions (2 accommodation and 13 treatment sessions). Although all patients completed 15 voice therapy sessions, no patient progressed through all steps of the vocal exercise program within the prescribed time frame of 15 sessions. On average, patients completed 9 of 14 steps (range, 7-10 steps). The mean (SD) NMES amplitude during these sessions was 9.5 (3.3) mA (range, 3-14 mA).

**OUTCOME MEASURES IMMEDIATELY AFTER TREATMENT**

**Maximum Phonation Time**

All 6 patients increased MPT for sustained /i/. Five of 6 patients also increased MPT for sustained /a/. The mean MPT for the group increased 38.4% over baseline for sustained /i/ and 42.5% over baseline for sustained /a/ (Table). The increased MPT for /i/ was statistically significant ($z=-2.201$, $P=.03$). The increased MPT for /a/ trended toward statistical significance ($P=.08$). A modest effect was demonstrated in MPT change for /i/ (Hedges' $g$, 0.65; 95% confidence interval, −0.56 to 1.75).24

**Highest Attainable Pitch**

Because of significant baseline aperiodicity in subject phonation, HAP data were complete for only 3 of 6 patients. Given these limited data points, no statistical analysis was performed. Group data from the remaining patients showed that the mean HAP for /i/ increased by 13.4%, while the mean HAP for /a/ decreased 23.6% following voice therapy (Table).

**Patient Perception of Voice (VHI)**

Five of 6 patients perceived their voices to have improved following voice therapy. The VHI (total) improved (ie, decreased a mean of 12.17 points [range, 3-17 points]) between pretreatment and posttreatment assessments (Table). This improvement trended toward significance ($z=-1.787$, $P=.07$).

**Pulmonary Function**

Group baseline FEV1% decreased 0.05% immediately following voice therapy. The VHI (total) improved (ie, decreased a mean of 12.17 points [range, 3-17 points]) between pretreatment and posttreatment assessments (Table). This change was not statistically significant.

**Laryngeal Configuration During Phonation**

Twelve video pairs directly compared pretreatment vs posttreatment laryngeal configuration during phona-

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### Table. Outcome Among 6 Patients During the Study Period

<table>
<thead>
<tr>
<th>Outcome Measure</th>
<th>Baseline</th>
<th>After Voice Therapy</th>
<th>3-Month Follow-up</th>
<th>Posttreatment P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum phonation time, s</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>/i/</td>
<td>10.16 (5.84)</td>
<td>14.06 (6.20)</td>
<td>15.01 (8.08)</td>
<td>.03</td>
</tr>
<tr>
<td>/a/</td>
<td>8.23 (2.72)</td>
<td>11.73 (4.77)</td>
<td>12.85 (7.23)</td>
<td>.08</td>
</tr>
<tr>
<td>Highest attainable pitch, Hz (n=3)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>/i/</td>
<td>275.56 (93.05)</td>
<td>312.46 (191.73)</td>
<td>359.32 (112.37)</td>
<td>NA</td>
</tr>
<tr>
<td>/a/</td>
<td>265.29 (76.63)</td>
<td>202.81 (108.24)</td>
<td>282.27 (66.09)</td>
<td>NA</td>
</tr>
<tr>
<td>Voice Handicap Index</td>
<td>41.17 (19.89)</td>
<td>29.00 (15.60)</td>
<td>27.17 (17.16)</td>
<td>.07</td>
</tr>
<tr>
<td>FEV1%</td>
<td>87.92 (0.10)</td>
<td>87.87 (0.10)</td>
<td>92.79 (0.13)</td>
<td>.92</td>
</tr>
</tbody>
</table>

Abbreviations: FEV1%, ratio of forced expiratory volume in the first second of expiration to forced vital capacity; NA, not applicable.
tion. Glottal closure was rated for 9 of 12 video pairs. Three video pairs were judged as “cannot see” for this variable. The posttreatment video demonstrated better glottal closure in 8 of 9 video pairs. Supraglottic compression was rated for all 12 of the video pairs comparing pretreatment vs posttreatment laryngeal configuration during phonation. The posttreatment video was identified as demonstrating less supraglottic compression in 7 of 12 video pairs. Interrater reliability was excellent for glottal closure ratings (κ=0.81) and moderate for supraglottic compression ratings (κ=0.57). 25

Outcomes at the 3-Month Follow-up

All 6 patients returned for the 3-month follow-up assessment. All treatment effects were maintained or enhanced, as no significant differences were noted in acoustic, pulmonary, or patient-centered outcome measures between the posttreatment and 3-month follow-up evaluations (Table). Furthermore, change in both laryngeal configuration variables was also maintained or enhanced at the 3-month follow-up assessment. For this analysis, 9 posttreatment videos previously used to rate pretreatment vs posttreatment glottal closure were compared with their corresponding 3-month follow-up video. Among these 9 new video pairs, glottal closure was rated in 6; the remaining 3 were judged as “cannot see” for this variable. The 3-month follow-up video was identified as demonstrating better glottal closure in 4 of 6 video pairs and as “no difference” in 1 video pair. Therefore, 5 of 6 endoscopic examinations demonstrated maintenance of the treatment effect for glottal closure. Similarly, 12 posttreatment videos used to rate pretreatment vs posttreatment supraglottic compression were used to compare posttreatment and 3-month follow-up evaluations. From these video pairs, the 3-month follow-up video demonstrated less supraglottic compression in 5 of 12 pairs and was judged as “no difference” in an additional 2 pairs. Therefore, 7 of 12 endoscopic examinations demonstrated maintenance of the treatment effect for supraglottic compression.

COMMENT

This prospective case series demonstrated that a standardized voice therapy protocol (based on exercise principles and using adjunctive NMES) increased MPT and glottal closure and decreased supraglottic compression in patients with dysphonia from bowed vocal folds, without significant complications or change in underlying pulmonary function. In addition, significant change in VHI revealed that patients perceived their voices to be improved following the voice therapy program. These outcomes were maintained or enhanced at the 3-month follow-up.

Increased MPT and glottal closure without underlying change in pulmonary function imply that this voice therapy program decreased vocal fold bowing. Mechanisms of these changes may have included enhanced thyroarytenoid or cricothyroid activity. In an investigation of the mechanisms of true vocal fold bowing, Tanaka et al26 found that bowing was directly related to thyroarytenoid muscle activity. Using laryngeal electromyogra-
itors suggest that the combination of NMES and vocal exercise may have helped increase cricoarytenoid lateralis muscle tension. Together, the present results and those by Ptok and Strack implicate positive laryngeal and voice outcomes from interventions combining voice therapy with NMES in different pathologic laryngeal conditions.

Strengths of this study include its standardized treatment protocol, homogeneous diagnostic population, blinded outcome assessment, and outcome measures across multiple domains. We acknowledge that this study has limitations inherent to a small uncontrolled clinical investigation. Case series do not have internal control comparisons and represent limited evidence for any given treatment. However, given the lack of published evidence supporting behavioral voice therapy for this clinical population, as well as the limited evidence supporting the use of NMES in voice therapy applications, we believe that this case series was an appropriate evidence supporting the use of NMES in voice therapy.

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To our knowledge, this prospective case series is the first to describe a successful standardized behavioral voice therapy protocol using adjunctive NMES for the treatment of dysphonia secondary to bowed vocal folds. Acoustic results showed significantly increased MPT, while endoscopic results revealed improved glottal closure and less supraglottic compression. Outcomes were maintained or improved at the 3-month follow-up after completion of the voice therapy program. As a clinical case series, this study serves as a first step in exploring the potential for behavioral voice therapy in the treatment of dysphonia due to bowed vocal folds. Future studies will investigate the separate effects of vocal exercise vs NMES for rehabilitating this patient population, as well as the effects of combined vocal exercise and NMES vs surgery.

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Author Contributions: Ms LaGorio and Dr Carnaby-Mann had full access to all the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis. Study concept and design: LaGorio, Carnaby-Mann, and Crary. Acquisition of data: LaGorio and Crary. Analysis and interpretation of data: LaGorio, Carnaby-Mann, and Crary. Drafting of the manuscript: LaGorio and Carnaby-Mann. Critical revision of the manuscript for important intellectual content: Carnaby-Mann and Crary. Statistical analysis: Carnaby-Mann. Obtained funding: Crary. Administrative, technical, and material support: Crary. Study supervision: Carnaby-Mann and Crary.

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