Chapter 21
Measurement of lesion size and vibratory dynamics characterization in a male child with vocal fold nodules, before & after voice therapy

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Abstract

It has been estimated that up to 16% of school-age children [1] suffer from voice problems. Long-standing untreated dysphonia can negatively affect children both psychologically and academically. Evaluation of vocal fold (VF) structure and cycle-to-cycle vibratory motion through techniques of direct visualization of the VF is vital for appropriate clinical assessment and measurement of treatment outcomes. In this chapter, we describe the use of high-speed videoendoscopy combined with custom developed laser projection for evaluation of quantitative changes in the lesion size and in the opening and closing phase dynamics of the glottal cycle before and after voice therapy in a child with VF nodules.

Keywords: pediatric high-speed videoendoscopy, VF nodules, lesion size, VF kinematics, voice therapy

Introduction

In the past twenty years, the use of high-speed videoendoscopy has been extensively used for investigating normal and disordered VF vibratory motion in adults [2-10]. More recently, there is emerging evidence on the use of high-speed videoendoscopy for evaluation of VF vibratory motion in children with and without voice disorders [11-15]. Currently, the clinically available high-speed videoendoscopy systems are able to record VF vibratory motion at up to 8000 f/s. This high temporal resolution is critical for obtaining valid information regarding vibratory function in children because often children are unable to produce phonations of greater than 2-3 seconds with a rigid or a flexible endoscope in place. Short phonation time on visual examination often results in non-interpretable findings on videostroboscopy. In this chapter, we describe the use of high-speed videoendoscopy for measurement of vibratory motion and lesion size before and after voice therapy (VTx) in a child with VF nodules.

Method

A 10-year-old male child with bilateral VF nodules underwent a total of eight 60-minute VTx sessions at the Indiana University, Department of Speech and Hearing Clinic. VTx sessions were conducted once a week. Lessac-Madsen Resonant Voice Therapy approach [16] was used. Pre- and post-VTx visualization of the VF were obtained using high-speed videoendoscopy (Model 9710, PENTAX Medical, Montvale, NJ, USA). A 10 mm rigid 70° endoscope was used to visualize the VF during sustained phonation of the vowel /i/ at
subject selected typical pitch and loudness level. High-speed videendoscopy was recorded for 4000 f/s for a total duration of 4 seconds using the black and white camera. Additionally, the VF were visualized during rest breathing using a custom developed laser endoscope coupled with the high-speed camera for lesion size measurements. Lesion size and kinematic parameters of opening and closing phases of the glottal cycle were obtained before and after VTx.

**Lesion size estimation**

The custom developed laser projection device reported in Patel et al. [13] was modified by Green Light Optics (Cincinnati, OH, USA) to address issues of poor stripe visibility and to increase the likelihood of having the stripes fall on the VF. The modifications included replacing the target grating with a smaller pitch and confining light to a smaller area to improve brightness. The useful stripes were visible up to 500 f/s. Additionally, the laser unit was removed from the body of the endoscope and coupled to the endoscope through a fiber to improve ergonomics. This resulted in an easier to manage unit and increased the ease of pointing the striped patch on the fold (Figure 1).

![Figure 1. Custom developed laser projection unit.](image)

The size of the nodules was measured as length in millimeters along the transverse and sagittal axes. The transverse and sagittal lengths were first measured in pixels and then converted to millimeters by scaling with a pixel-to-millimeter ratio [13]. The pixel-to-millimeter ratio was estimated by finding the calibrated position of the projected vertical patterns. In Figure 2, the area of the nodule is demarcated using a circle. The white and the red-colored line segments represent transverse and sagittal axes, respectively. Estimates of lesion size in the transverse and sagittal axis was obtained for left and right VF separately. The lesion size measurements were averaged across three frames per recording to minimize and report on the measurement errors.
Image segmentation and estimation of the kinematic parameters was performed using a custom developed image processing tool called the Vocal Cord Analyzer (VCA-beta) [17]. The kinematic parameters were estimated from the displacement trajectories obtained from the mid-membranous portion of the VF. All kinematic features were estimated from 30 consecutive cycles of sustained phonation where the time scale of each cycle was normalized by the pitch period and the spatial distances were normalized by the glottal length. This scaling allowed for objective comparisons between different scans and populations when additional instrumentation to measure physical size is unavailable. The scaling by the glottal length removes the dependence on pixel size (which can vary based on depth of image plane) and results in quantities related to percent displacement of VF tissue rather than absolute distance. The scaling by pitch period results in parameters related to energy distributions over the cycle period. The parameters extracted from this analysis provide quantitative measures of qualitative dynamics observed on high-speed videodendoscopy, such as glottal area geometries and opening/closing phase dynamics, thereby facilitating comparisons of populations and assessments of treatment progress over time.

The following parameters were used to quantify the effects of voice therapy in a child with VF nodules: normalized peak displacement, normalized peak opening/closing velocity, normalized average opening/closing velocity, peak-to-average closing velocity ratio, open quotient, and speed quotient. The definition of the above parameters and the corresponding normative values of children and adults without voice disorders are obtained from Patel et al. [17]. Each parameter was estimated from the pixel displacement of the VF edge relative to a medial line during steady-state phonation of the left and right VF [17]. The glottal length was extracted in pixels and the displacement was divided by this quantity to result in the displacement waveforms. Each glottal cycle is scaled to 1 on the time axis (normalized by pitch), so that the axis represents phase or percent of the phonation cycle.
All estimates in Table 1 were results of averaging over 30 cycles and the maximum value between the right and left VF was then taken for the parameters used to represent the phonation segment [17]. The normalized average opening velocity was computed from the normalized peak displacement divided by the percentage of the cycle time for the opening phase [17]. The normalized peak opening velocity is the maximum derivative of the glottal displacement waveform during the opening phase. Analogous quantities were computed for the closing phase of the glottal cycle. The open quotient [10] and speed quotients [17] were also computed for comparison purposes. The kinematic parameter of peak-to-average closing velocity [10] was derived by dividing the normalized peak closing velocity by the average closing velocity. This indicates the level of velocity changes over an opening or closing phase. A value of 1 would imply a constant velocity between the complete open and close points of the glottal cycle. A value greater than 1 implies forces acting on the VF during its motion (as a change in velocity is the result of force). Large values of this parameter are hypothesized to result from large changes in the elastic properties of the VF during its extension or changes in the airflow/turbulence.

### Table 1. Mean values of the kinematic features before and after voice therapy in a 10-year-old male child with VF nodules.

<table>
<thead>
<tr>
<th></th>
<th>Pre Therapy</th>
<th>Post Therapy</th>
<th>Typical Kids</th>
<th>Adult Males</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normalized Peak Displacement</td>
<td>0.2398</td>
<td>0.1348</td>
<td>0.14±0.04</td>
<td>0.12±0.05</td>
</tr>
<tr>
<td>Normalized Peak Opening Velocity</td>
<td>1.1978</td>
<td>0.6384</td>
<td>0.7±0.32</td>
<td>0.75±0.29</td>
</tr>
<tr>
<td>Normalized Average Opening Velocity</td>
<td>0.6079</td>
<td>0.3519</td>
<td>0.48±0.22</td>
<td>0.45±0.15</td>
</tr>
<tr>
<td>Normalized Peak Closing Velocity</td>
<td>1.3331</td>
<td>1.0346</td>
<td>0.81±0.32</td>
<td>0.72±0.36</td>
</tr>
<tr>
<td>Normalized Average Closing Velocity</td>
<td>0.3734</td>
<td>0.5179</td>
<td>0.56±0.22</td>
<td>0.4±0.18</td>
</tr>
<tr>
<td>Peak-to-Average Closing Velocity</td>
<td>3.6717</td>
<td>2.0445</td>
<td>1.432±0.079</td>
<td>1.467±0.363</td>
</tr>
<tr>
<td>Open Quotient</td>
<td>0.2770</td>
<td>0.3540</td>
<td>0.592±0.13</td>
<td>0.555±0.36</td>
</tr>
<tr>
<td>Speech Quotient</td>
<td>1.549</td>
<td>2.1259</td>
<td>1.56±0.49</td>
<td>1.13±0.31</td>
</tr>
</tbody>
</table>

### Results

#### Lesion size

The size of the nodules decreased bilaterally along the transverse axis following VTx (Figure 3). The left VF nodule size in the transverse direction was 0.539 ± 0.070 mm (CI 95% = 0.174) before therapy and was 0.2716 ± 0.051 mm (CI 95% = 0.126) following VTx. The left VF nodule size in the vertical/sagittal axis was 1.317 ± 0.112 mm (CI 95% = 0.277) before therapy, whereas the post therapy nodule size in the vertical/sagittal axis was 1.256 ± 0.077 mm (CI 95% = 0.191). The right VF nodule size in the transverse direction was 0.602 ± 0.105 mm (CI 95% = 0.261) before VTx and was 0.255 ± 0.063 (CI 95% = 0.156) post-VTx. The right VF nodule size in the vertical/sagittal axis was 1.50 ± 0.343 (CI 95% = 0.853) before VTx, whereas the post-VTx nodule size in the vertical/sagittal axis was 1.88 ± 0.232 (CI 95% = 0.576).
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Figure 3. Pre- and post-VTx lesion size in a 10-year-old male child with VF nodules.

Kinematic parameters

All kinematic parameters of Table 1 show a trend towards values from the normal population post-treatment. All except the open quotient and normalized peak closing velocity result in values within the 95% confidence limits of the mean normal population. The normalized peak displacement shows the second largest change with a reduction of 44%. The normalized peak displacement directly impacts the normalized velocity parameters, which also showed a large percentage change. The normalized peak opening velocity post therapy showed the largest change with a reduction of 47%, while and the normalized average opening velocity decreased by 42%.

For the closing phase the normalized peak closing velocity decreased by 22%, which did not result in a value near the normal population. However, the average closing velocity did increase by 39%. These changes are consistent with the glottal displacement waveform shown in Figure 4a and 4b with a sequence of typical phonation cycles before and after treatment. Note the shorter intervals for the closing phase as well as a smoother overall trajectory with a shorter open phase post voice therapy. The smaller peak-to-average closing velocity for post-treatment follows the increased average closing velocity post treatment.

Figure 4a. Pre-therapy displacement waveforms for L/R VF.
Discussion

The goal of this study was to evaluate the lesion size and kinematic parameters of VF motion before and after voice therapy in a child with VF nodules. Measurement of lesion size using custom developed laser endoscope revealed that the size of the nodule reduced following eight sessions of voice therapy. However, the nodules were not completely resolved. The greatest reduction in the lesion size was along the transverse (horizontal) direction compared to the sagittal (vertical) direction.

Quantitative measurements of the opening and closing phase kinematics revealed a greater reduction in the spatiotemporal features of impact stress (e.g., normalized peak displacement, normalized peak opening velocity, normalized peak closing velocity, normalized average opening velocity, peak-to-average closing velocity, normalized average opening velocity, peak-to-average closing velocity) following voice therapy resulting in smoother opening and closing phase trajectories. Qualitative visual-perceptual observations of vibratory motion on high-speed videoendoscopy indicated a shutter-like closure for the VF motion pre-treatment and a smoother closure post treatment. This is consistent with the decrease in peak velocities for both the opening and closing phases following voice therapy. The relative-velocity trajectories pre-treatment (Figure 5a) indicate a more rapid velocity in the initial part of the opening phase and then a slow down as the fold reaches its peak displacement. A similar pattern occurs for the closing phase of the glottal cycle. One reason for the observed variations in the pre-treatment velocity trajectory is the result of the large normalized peak displacement, which represents the percentage of tissue displaced. Small normalized displacements are more likely to maintain consistent elastic and restorative forces, whereas large displacements result in more severe tissue compression and displacement in the orthogonal (vertical) planes (not captured in the video). These changes fold elasticity during displacement resulting in the more severe velocities changes as observed in the pre-therapy velocity (Figure 5a) and displacement (Figure 4a) trajectories. Clearly as the fold reaches its displacement limit, it no longer absorbs the energy from the air flow and slows down (fold remains in extended position longer/slower resulting in a higher peak velocity), whereas for smaller displacements the elastic force is more consistent resulting in a more even energy exchange in the extended position. In addition, inflammation and stiffness from

![Figure 4b. Post-therapy displacement waveforms for L/R VF.](image-url)
the nodule creates non-uniformity in the elastic forces along the fold as well further adding to the uneven trajectory of the VF prior to voice therapy. While kinematic parameters are normalized and do not indicate absolute velocities, distances, and forces, they provide quantitative information regarding the relative trends for the opening and closing phases of the glottal cycle within the same subject.

**Figure 5a.** Pre-therapy normalized velocity waveforms for L/R VF.

**Figure 5b.** Post-therapy normalized velocity waveforms for L/R VF.

The therapy likely helped the subject reduce subglottal pressure that was reflected in the smaller peak displacements, which in turn lead to the smoother trajectories reflected in the kinematic parameters. Simultaneous measurements of respiratory function along with high-speed imaging are needed to further address the physiological mechanisms other than lesion size for the change in kinematic trajectories following treatment. The post treatment shows an increase in the normalized average closing velocity (Figure 5b).
This is somewhat anti-intuitive given that more energy (relatively speaking) is expended in the closing phase which suggests more impact on the nodules. However, this range is observed for normal children. The increase in normalized average closing velocity after treatment could be a result of reduced inflammation from the nodule increasing not only the uniform elasticity of the fold, but the overall elasticity.

This case study demonstrates the utility of the normalized kinematic features along with results from an experimental baseline to assess response to voice treatment. Further, large-scale studies are clearly warranted. However, the initial findings presented in this chapter suggest the usefulness of high-speed videoendoscopy for clinical investigation of changes in VF physiology before and after voice therapy in a child with VF nodules.

References
