Vocal Fold Vibration Following Surgical Intervention in Three Vocal Pathologies: A Preliminary Study

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Summary: High-speed videoendoscopy captures the cycle-to-cycle vibratory motion of each individual vocal fold in normal and severely disordered phonation. Therefore, it provides a direct method to examine the specific vibratory changes following vocal fold surgery. The purpose of this study was to examine the vocal fold vibratory pattern changes in the surgically treated pathologic vocal fold and the contralateral vocal fold in three vocal pathologies: vocal polyp (n = 3), paresis or paralysis (n = 3), and scar (n = 3). Digital kymography was used to extract high-speed kymographic vocal fold images at the mid-membranous region of the vocal fold. Spectral analysis was subsequently applied to the digital kymography to quantify the cycle-to-cycle movements of each vocal fold, expressed as a spectrum. Surgical modification resulted in significantly improved spectral power of the treated pathologic vocal fold. Furthermore, the contralateral vocal fold also presented with improved spectral power irrespective of vocal pathology. In comparison with normal vocal fold spectrum, postsurgical vocal fold vibrations continued to demonstrate decreased vibratory amplitude in both vocal folds.

Key Words: High-speed videoendoscopy–Digital kymography–Vocal fold vibration–Laryngeal surgery–Vocal fold vibratory spectrum.

INTRODUCTION

Postoperative assessment of vocal fold vibration is imperative from a surgical perspective as well as a rehabilitative perspective. It determines surgical success, candidacy for voice therapy, and whether further medical management is needed. Current postoperative assessments of vocal fold vibration consist of subjective analysis utilizing videostroboscopy, self-assessment tools, or audio or aerodynamic instrumental analysis. In many cases, the patient is left to making a simple self-perception judgment of "better, worse, or the same."

High-speed videoendoscopy (HSV) captures data at more than 2000 frames per second, which allows direct visualization of the entire cycle-to-cycle vibratory motion of the left and right vocal fold in normal speaking adults[1–8] and in disordered phonation.[9–15] The use of HSV has provided significant utility in understanding the etiology of disorders on vocal fold vibration, as well as provided close examination of aperiodic vibrations that are difficult to capture on standard stroboscopy measures.[9–15]

Digital kymography uses HSV to examine the precise vibratory characteristics of each vocal fold at selected locations along the vocal folds.[7,9,14,15] The resulting values can be analyzed as a vibratory spectrum.[7,9] In the vibratory spectrum, spectral power in the fundamental frequency ($F_0 = H_1$) has been associated with the degree of vocal fold excursion, whereas the energy of the higher harmonics has been associated with the discontinuity that occurs with vocal fold impact.[9,16] Therefore, digital kymography spectrum is a useful tool to objectively quantify precise vocal fold vibration and offers an ideal methodology to examine the specific changes in vibratory behavior of the vocal folds following surgical intervention.[9] Quantification of vibration in each vocal fold using HSV is now practical.

Previous studies using HSV demonstrated improvements in vocal fold vibration following medical intervention. Kunduk et al[11] have shown improved amplitude and symmetry of vocal fold vibration following surgical resection of vocal fold polyp at 1 month and 3 months postsurgery. Kimura et al[13] demonstrated improvements in vocal vibratory patterns toward symmetry in patients with unilateral vocal fold paralysis following collagen injection. Chen et al[9] have shown improved vibratory amplitude and symmetry in three types of vocal fold pathologies following surgical treatment, with the most remarkable change noted at the mid-membranous region of the vocal fold. Although these studies unequivocally demonstrate improved vibratory motion in both vocal folds, little is known about the specific vibratory changes in each vocal fold. Understanding changes in the treated as well as the contralateral unoperated vocal fold may assist in surgical management and offer insight as to the basis of remaining dysphonia or the lack of it. Therefore, the goal of this preliminary study was to examine direct vocal fold vibratory changes in the treated pathologic vocal fold and the contralateral vocal fold following surgical intervention.

METHODS

Three subjects with identifiable mid-vocal fold benign lesions, two with unilateral vocal fold paresis, one with unilateral vocal fold paralysis, and three with vocal fold scar were studied prior to and following surgical intervention. Vocal pathology was diagnosed by a board-certified otolaryngologist. These diagnostic types were intentionally selected to represent varying levels of vocal fold pathology (refer to Table 1 for laryngeal etiology, age, diagnosis, and the type of surgical intervention). Two male and one female normal adult subjects were also recorded for comparison. HSV was obtained using standard videostroboscopy procedures.

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TABLE 1.
Information on Pathologic Group, Age, Diagnosis, and Type of Surgical Intervention Received

Subject	Age	Diagnosis	Diagnostic Information	Surgical Intervention
M1	42	Polyp	L VF polyp	Polyp excision using cold instruments
M2	45	Polyp	R VF polyp	Polyp excision using cold instruments
M3	47	Polyp	L VF polyp	KTP laser
S1	85	Scar	R VF hyperkeratosis	KTP laser
S2	71	Scar	L VF scar with recurrent keratosis	KTP laser
S3	68	Scar	L VF scar with R VF bowing	KTP laser
P1	45	Paralysis	R VF paralysis with R sulcus vocalis	Injection laryngoplasty
P2	49	Paresis	L VF paresis	Injection laryngoplasty
P3	67	Paresis	L VF paresis	Injection laryngoplasty

Abbreviation: KTP, potassium titanyl phosphate; L, left; R, right; VF, vocal fold.

High-speed video recording

HSV was recorded with the Kay Elemetrics High-Speed Digital Imaging (HSDI) system (KayPENTAX Photron Motion, Montvale, NJ, USA), which consisted of a 90° rigid endoscope (Model 9100) and a 300-Watt Xenon light source. The HSDI system captured grayscale images at a rate of 2000 frames per second, with a spatial resolution of 256×120 pixels rotated to a vertical position. Videostrobolaryngoscopy was conducted utilizing a rigid endoscope, with the subject sustaining /i/ at a comfortable pitch and loudness. A contact microphone was attached at the neck to monitor pitch and a second microphone was placed 6 inches from the lips to monitor intensity. The HSV samples were obtained when the examiner observed a clear and full view of the larynx. Six continuous 2-second tokens of the vowel were recorded. The three best tokens with a clear and full view of the vocal folds were saved onto a hard drive for analysis. All subjects tolerated the data collection procedure without any difficulties.

Data analysis

Kymography image processing

HSV images were preprocessed with video editing software (*VirtualDub* v.1.9.11 (virtualdub.org)). Brightness and contrast of the glottis and vocal folds were adjusted for optimal edge detection. Image rotation was implemented, as needed, to ensure vertical alignment of the image. A 400- to 500-frame video segment that captured a full view of the vocal folds with minimal movement of the subject was extracted from the recorded HSV samples. *Kay's Image Processing Software* (*KIPS*, Model 9181) was used to generate the kymogram. Digital kymograph was created by placing a transverse line across the mid-membranous region of the glottis (Figure 1A and B), which has been reported to be the area of maximal vocal fold contact.[17] Edge detection was applied to trace the vocal fold edges (Figure 1C). Kymograph analysis of the vibratory samples is dependent on the delineation of the vocal fold edge from HSV.[18] Therefore, manual corrections function was utilized, as needed, to ensure correct tracing of the vocal fold edges. Kymograph edge analysis function was subsequently applied on the kymogram. The resulting values were kymograph edge data, which showed the coordinate values of the left and right edges of the vocal fold across time (Figure 1D). Fourier transform function was subsequently applied. This resulted in a spectrum ranging from 0 Hz to 1000 Hz for the left and right edges of the vocal folds (Figure 1E).

Spectral data analyses

Three values were extracted from the left and the right vocal fold vibratory spectrum for quantitative analysis: the peak power values of the fundamental ($F_0 = H_1$), second harmonic (H_2), and third harmonic (H_3). Twenty-five percent of the postprocessed 500-frame HSV tokens were randomly selected and reanalyzed by the same experimenter to evaluate the error of measurement. Comparison of the H_1, H_2, and H_3 values between the original and reanalyzed sample yielded a reliability of 87%.

The following vocal fold vibratory parameters were extracted at baseline and postintervention: (1) total spectral power,

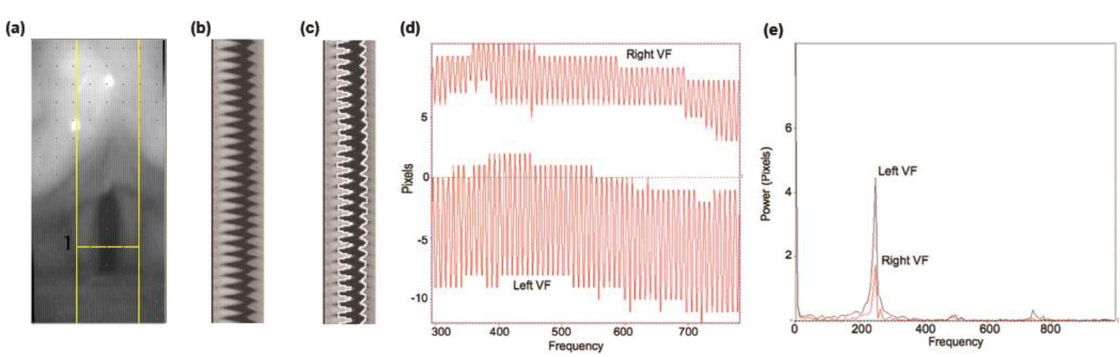

FIGURE 1. Methods to obtain spectral analysis of digital kymography in subject P2 (see text for descriptions).

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