Visualization and Estimation of Vibratory Disturbance in Vocal Fold Scar Using High-Speed Digital Imaging

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Summary: Objective. To explore the method to visualize and quantify the abnormality of vocal fold vibration in vocal fold scar (VFS) using high-speed digital imaging (HSDI).

Methods. HSDI was performed on 12 patients (2 men and 10 women) with VFS and 46 vocally healthy subjects (17 men and 29 women), and the obtained data were quantitatively evaluated by frame-by-frame analysis, laryngotopography (LTG), single-line and multiline kymography, and glottal area waveform.

Results. Visualization of a scarred area was feasible in 75% of VFS in the present study using LTG. Quantitative HSDI analysis revealed that VFS had poorer glottal closure (eg, larger open quotients, larger minimal glottal area), reduced vibration in a scarred area (eg, smaller mucosal wave magnitude, mucosal wave persistence, lateral peak index), and greater asymmetry (eg, amplitude difference, mucosal wave magnitude difference, lateral phase difference) than the control group. Correlation study revealed moderate correlations between HSDI-derived parameters and conventional acoustic or aerodynamic parameters (eg, period perturbation quotient).

Conclusions. HSDI is considered to be useful in the diagnosis of VFS, visualization of a scarred area, and quantification of vibratory abnormality.

Key Words: Vocal fold scar–High-speed digital imaging–Laryngotopography–Kymography–Glottal area waveform.

INTRODUCTION

Vocal fold scar (VFS) or scarring is a voice disorder caused by the formation of scar tissue and structural disorganization in the lamina propria of the vocal fold.[1–5] These alterations lead to impaired vocal fold vibration, resulting in dysphonia. The common causes of VFS are phonosurgery, direct vocal fold injury (eg, endotracheal intubation), and phonotrauma (eg, abuse of the voice). Additionally, smoking, diabetes, immune deficiency, reflux laryngitis, and other systemic diseases (eg, sarcoidosis) can unfavorably affect the healing process and predispose the vocal folds to scarring.[1,5]

The diagnosis of VFS is made through careful history taking, a full voice-lab work up, and visualization of vocal fold or vibratory assessment by indirect laryngoscopy or videostroboscopy in the clinical routine, although the exact diagnosis is based on a direct microlaryngoscopy with palpation of the vocal folds with microinstruments.[5] Typical vibratory characteristics of VFS observed by videostroboscopy include impaired glottal closure with a spindle-shaped glottal gap, a reduced or absent amplitude and mucosal wave at the site of scarring, and asymmetric and irregular vocal fold vibrations.[2,5] However, although in some cases with obvious causes, such as those following cordectomy, the diagnosis of VFS is not difficult, identification of VFS can be challenging in other cases. This is partly due to failure of synchronization during videostroboscopic examination, especially in patients with an aperiodic voice signal. Furthermore, because videostroboscopic evaluation is performed in a subjective and qualitative manner, subtle vibratory derangement may be left unnoticed.

In contrast, high-speed digital imaging (HSDI) can be more suitable for the vibratory evaluation of VFS because it can visualize both regular and irregular vocal fold vibrations with high temporal resolution, and there are various analytical methods for HSDI that allow multifaceted, quantitative documentation of vocal fold vibrations.[6,7] Until recently, there were only some case reports on a limited range of vibratory features.[8–10] In 2010, Mehta et al[11] performed VFS in 14 patients after angiolytic laser surgery for early glottic cancer using digital kymography. In 2012, Piazza et al[12] reported on VFS in eight patients after phonosurgery for benign vocal fold diseases using videokymography.[12] Unfortunately, the quantitative parameters assessed in these studies were not sufficient to properly describe the previously mentioned vibratory characteristics of VFS. In addition, kymographic evaluation of one horizontal level, as used in these studies, does not provide data on the spatial characteristics of VFS.

Furthermore, there is little knowledge of the relationship between HSDI parameters and acoustic or aerodynamic parameters in VFS, although this is essential for understanding its pathophysiological characteristics.

On the basis of the previous information, the present study investigated the following hypotheses: first, HSDI has a potential usefulness in the evaluation of VFS; second, quantitative HSDI parameters can differentiate vibratory characteristics between normal subjects and patients with VFS; and third, abnormality in HSDI parameters has correlation with voice outcome.

To prove these hypotheses, HSDI data from patients with VFS and age-matched vocally healthy subjects were quantitatively compared using visual-perceptual rating, laryngotopography (LTG), digital kymography, and glottal area waveform

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(GAW). Furthermore, HSDI parameters were compared with perceptual/aerodynamic/acoustic measures to clarify relationships between vibratory parameters and resultant vocal outcome in VFS.

MATERIALS AND METHODS

Subjects

Patients were enrolled in this study if they visited the Voice Outpatient Clinic of the Department of Otolaryngology and Head and Neck Surgery at the University of Tokyo Hospital (Tokyo, Japan) between 2006 and 2013 and were diagnosed with VFS. Diagnosis of VFS was based on careful history taking, acoustic and aerodynamic evaluation, and videostroboscopy. The diagnosis was made by consensus among three or four certified otorhinolaryngologists specializing in vocal treatment. The control group was gender- and age-matched vocally healthy subjects without vocal complaints, a history of laryngeal disorders, or laryngeal abnormalities on laryngoendoscopy.

All subjects were required to sign a consent form that was approved by our institutional review board. A total of 12 patients with VFS (10 women and 2 men) aged from 25 to 68 years and 46 vocally healthy subjects (27 women and 19 men) aged from 21 to 81 years were enrolled in this study.

TABLE 1.
Clinical Data of All Participants Are Summarized

Parameter (U)	Control (n = 46)	Vocal Fold Scar (n = 12)	P Value
Age (y)	47 ± 23	52 ± 14	0.456
Gender (n)	Male 17, female 29	Male 2, female 10	0.189
MPT (s)	22.8 ± 8.8	13.6 ± 4.7	<0.001***
MFR (mL/s)	132 ± 38	221 ± 166	0.001**
AA-F_0 (Hz)	187 ± 56	209 ± 43	0.220
APQ (%)	3.1 ± 2.6	5.0 ± 1.8	0.026*
PPQ (%)	0.29 ± 0.36	2.16 ± 1.82	<0.001***
HNR (dB)	22.5 ± 4.3	7.6 ± 3.1	<0.001**
Grade	0.65 ± 0.57	1.75 ± 0.87	<0.001***
Roughness	0.65 ± 0.57	1.75 ± 0.87	<0.001***
Breathiness	0.30 ± 0.47	1.25 ± 0.87	<0.001***

Notes: Values signify "mean ± standard deviation." The column for P value shows the P values of chi-squared test (gender) and Student t test (the rest) between control and vocal fold scar groups.
Abbreviations: MPT, maximum phonation time; MFR, mean flow rate; AA-F_0, fundamental frequency in acoustic analysis; APQ, amplitude perturbation quotient; PPQ, period perturbation quotient; HNR, harmonics-to-noise ratio.
*P < 0.05; **P < 0.01; ***P < 0.001.

Background data

Vocal function and voice quality were evaluated by measuring perceptual, aerodynamic, and acoustic parameters. As perceptual parameters, the G, R, and B scales from the GRBAS scale were rated. A sustained phonation of /a/ at a comfortable frequency and sound pressure level was rated by at least three otolaryngologists, and the rating was determined in the agreement of all raters. Aerodynamic parameters, including the maximum phonation time and mean flow rate, were measured with a Nagashima PE-77E Phonatory Function Analyzer (Nagashima Medical Inc., Tokyo, Japan). Acoustic parameters included fundamental frequency, amplitude perturbation quotient, period perturbation quotient, and harmonics-to-noise ratio. These parameters were measured at the University of Tokyo by using a dedicated software program. The previously mentioned voice parameters were selected because they were most routinely evaluated in the clinical setting in Japan.

Table 1 summarizes the results of aerodynamic and acoustic studies. There were significant differences of the mean flow rate, amplitude perturbation quotient, period perturbation quotient, harmonics-to-noise ratio, and the G and R scales of the GRBAS scale. The scores for the Voice Handicap Index-10 and voice-related quality of life were 16.1 ± 11.5 and 16.4 ± 11.1, respectively, whereas the rate of synchronization of VFS with videostroboscopy (LS-3A, Nagashima Medical Inc., Tokyo, Japan) was 77.8%.

High-speed digital imaging

A high-speed digital camera (FASTCAM-1024PCI; Photron, Tokyo, Japan) was connected to a rigid endoscope (#4450.501, Richard Wolf, Vernon Hills, IL) via an attachment lens (f = 35 mm; Nagashima Medical Inc., Tokyo, Japan). Recording was performed under illumination with a 300-W xenon light source at a frame rate of 4500 fps and a spatial resolution of 512 × 400 pixels, using an eight-bit gray scale and a recording duration of 1.86 seconds. High-speed digital images were recorded during sustained phonation of the vowel /i/ at a comfortable frequency and comfortable intensity, and a sequence of stable vocal fold vibrations was selected for analysis.

Aerodynamic and acoustic studies were performed approximately 30 minutes before HSDI because simultaneous recording was not available at our institution. Both evaluations were done under conditions that were as similar as possible to allow comparison between the HSDI parameters and the aerodynamic/acoustic parameters.

HSDI analysis

The recorded HSDI data were evaluated by visual-perceptual rating,[13] LTG,[14] single-line/multiline digital kymography (SLK and MLK, respectively),[15,16] and GAW analysis.[17] The details of these methods have been described elsewhere.[13–17]

Size parameters were normalized by the vocal fold length (indicated by "N_L−," eg, N_L-amplitude mean), and time parameters were normalized by the glottal cycle (indicated by "N_G−," eg, N_G-lateral phase difference). Size and time parameters were also normalized by both glottal cycle and vocal fold length (indicated by "N_{GL}−," eg, N_{GL}-lateral phase difference).[15]

In the present study, analysis was focused on parameters that were considered to be related to the vibratory characteristics of