Quantitative Analysis of Vocal Fold Vibration in Vocal Fold Paralysis With the Use of High-speed Digital Imaging

***Akihito Yamauchi, †Hisayuki Yokonishi, *Hiroshi Imagawa, ‡Ken-Ichi Sakakibara, *Takaharu Nito, and §Niro Tayama,** *,†,§*Tokyo, Japan; and* ‡*Hokkaido, Japan*

Summary: Introduction. The goal of this work was to objectively elucidate the vibratory characteristics of vocal fold paralysis (VFP) using high-speed digital imaging (HSDI).

Methods. HSDI was performed in 29 vocally healthy subjects (12 women and 17 men) and in 107 patients with VFP (40 women and 67 men). Then, the HSDI data were evaluated by visual-perceptual rating, single-line kymography, multiline kymography, laryngotopography, and glottal area waveform analysis.

Results. Patients with VFP compared with vocally healthy subjects revealed more frequent incomplete glottal closure, greater asymmetry in amplitude, mucosal wave, frequency, and phase, as well as larger open quotient, smaller speed index, larger maximal and minimal glottal area, and smaller glottal area difference. Paralyzed vocal folds in VFP revealed reduced mucosal wave than nonparalyzed vocal folds in VFP or in intact vocal folds in vocally healthy subjects.

Conclusions. HSDI was effective in documenting the characteristics of vocal fold vibrations in patients with VFP and in exploring the vibratory disturbance for estimating the severity of dysphonia.

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

INTRODUCTION

For the appropriate management of disorders of the voice, direct observation and objective assessment of vocal fold vibration is indispensable. In routine clinical practice, videostroboscopy is most commonly employed for the observation of vocal fold vibrations because it provides full color images and high spatial resolution at a relatively low cost.[1] However, videostroboscopy can only be applied to assessment of stable and periodic vocal fold vibrations. Otherwise, reconstruction of illusory oscillatory image sequence based on the tracking of stable fundamental frequency fails, resulting in synchronization failure.[2] Necessity of stable fundamental frequency limits videostroboscopic examination in transient motions, such as vocal onset, vocal offset, glissando, and so forth.

For the observation of irregular or aperiodic vocal fold vibrations that are commonly associated with voice pathology or transient glottal phenomena, high-speed digital imaging (HSDI), which registers actual vocal fold vibration with its extremely high temporal resolution, is considered to be a superior method. Wider application offers more opportunity to evaluate vocal fold vibrations in clinical cases with various laryngeal pathologies.[3]

Furthermore, quantification of oscillatory characteristics is essential to enhance the objectivity and the validity of vocal fold vibration assessment. For the quantitative assessment, especially in the temporal domain, HSDI is advantageous over videostroboscopy because it registers the actual intra- or intercycle vibratory behavior.[2,4,5] In fact, to take this advantage into account, HSDI is preferable to videostroboscopy in normative studies as well.

Additionally, HSDI offers more various choices of analysis method than videostroboscopy, and thus more multifaceted information that might not be detected *via* videostroboscopy can be obtained by HSDI. Routinely, videostroboscopy is evaluated only by visual-perceptual rating,[1] or by glottal area waveform (GAW) or by kymography in some occasions.[6,7] On the other hand, HSDI is usually evaluated not only by visual-perceptual rating[4,8,9] but also by various other methods such as digital kymography,[10–12] laryngotopography (LTG),[13,14] phonovibrography,[15,16] and GAW.[8,17,18]

Vocal fold paralysis (VFP) is a common disorder of the voice, and visualization of vocal fold vibration constitutes an essential role to its management.[19,20] First, the diagnosis is established by a combination of laryngeal examination *via* usual endoscopy, videostroboscopy or HSDI, laryngeal electromyography, computed tomography scan, and so forth. Second, the quantitative observation of vocal fold vibrations in VFP allows the objective documentation of vibratory disturbance, estimation of degree of dysphonia, interindividual comparison, and evaluation of therapeutic outcome, which are getting more and more important these days against the background of worldwide trend for evidence-based medicine. For this purpose, HSDI that has a wider application, better capacity for objective quantification, and a greater methodological variety than videostroboscopy is a preferable choice.

Until recently, HSDI studies on VFP have generally been of a small sample size.[15,16,21–32] Schwarz et al quantified frequency, lateral phase difference, and amplitude difference in 15 patients with unilateral VFP in 2006.[33] Kimura et al also quantified the frequency

Accepted for publication October 22, 2015.

Presented at the 10th Pan European Voice Conference held in Prague, Czech Republic from August 21 to 24, 2013.

Disclosure: This research was not funded by any organization or grant. There are no conflicts of interest to be disclosed.

From the *The Department of Otolaryngology, The University of Tokyo Hospital, 3-7-1, Hongo, Bunkyo-Ku, Tokyo 113-8655, Japan; †The Department of Otolaryngology, The Tokyo Metropolitan Police Hospital, 4-22-1, Nakano, Nakano-Ku, Tokyo 164-8541, Japan; ‡The Department of Communication Disorders, The Health Sciences University of Hokkaido, 1757, Ataribetsucho-Kanazawa, Ishikari-Gun, Hokkaido 061-0293, Japan; and the §The Department of Otolaryngology and Tracheo-esophagology, The National Center for Global Health and Medicine, 1-21-1, Toyama, Shinjuku-Ku, Tokyo 162-8655, Japan.

Address correspondence and reprint requests to Akihito Yamauchi, The Department of Otolaryngology, The University of Tokyo Hospital, 7-3-1 Hongo, Bunkyo-ku, Tokyo, 113-8655, Japan. E-mail address: drachilles23@yahoo.co.jp

Journal of Voice, Vol. ■■, No. ■■, pp. ■■-■■

0892-1997

http://dx.doi.org/10.1016/j.jvoice.2015.10.015

in 17 patients with unilateral VFP in 2010.[34,35] Inwald et al investigated a large series of 184 patients with VFP (unilateral, 171; bilateral, 13) in 2011, and reported their quantitative HSDI parameters with the focus on acoustics based on GAW analysis.[8]

However, the HSDI-derived spatial parameters for vibratory characteristics that correspond to routinely investigated stroboscopic parameters (eg, asymmetry, amplitude, glottal closure, and mucosal wave) have not been fully explored. Specifically, quantification of vibratory characteristics attributed to VFP, such as glottal gap asymmetry in amplitude, mucosal wave, cycle-to-cycle aberrance, is expected to be useful in the evaluation of VFP.[19,20,34,35]

In addition, the association between HSDI-derived vibratory parameters and conventional voice parameters has not been fully investigated in patients with VFP. Correlation study between HSDI-derived vibratory parameters with perceptual/acoustic/aerodynamic measures provides us insights into the order of priority in vibratory parameters and the one-to-one correspondence between vibratory parameters and outcome voice data, which should expand the knowledge of pathophysiology of this clinical entity.

On the basis of these backgrounds, the present work explored the following hypotheses: first, HSDI has a potential usefulness in the evaluation of VFP; second, the differentiation between vocally healthy subjects and patients with VFP is feasible by quantifying HSDI-derived vibratory parameters; and third, there exist statistically significant correlations between HSDI parameters and conventionally measured indirect voice parameters.

To prove these hypotheses, in the present study, HSDI data from patients with VFP and age-matched vocally healthy normal subjects were analyzed by visual-perceptual rating, LTG, single-line kymography, multiline kymography, and GAW with the emphasis on vibratory features associated to VFP. Subsequently, vibratory differences among vocal folds in normal subjects, nonparalyzed vocal fold of VFP, and paralyzed vocal folds in VFP were compared to investigate the direct influence of paralysis on vibratory dynamics. In addition, correlation study was conducted between HSDI parameters and perceptual/aerodynamic/acoustic measures to clarify relationships between vibratory parameters of sound source and voice measures of outcome in VFP.

Therefore, the present study was performed to quantitatively elucidate the vibratory characteristics of VFP using multiple methods of HSDI analysis (an assessment form, single-line digital kymography [SLK] and multiline digital kymography [MLK], LTG, and GAW analysis), and to clarify the relationship between HSDI parameters and aerodynamic/acoustic measures.

MATERIALS AND METHODS

Subjects

Patients who 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 VFP were included in this study. As a control group, we recruited age- and gender-matched vocally healthy subjects without vocal complaints, a history of laryngeal disorders, or signs of laryngeal abnormality on laryngoendoscopy.

All subjects were required to sign a consent form that was approved by our institutional review board. A total of 107 patients with VFP (40 women and 67 men) aged between 22 and 85 years were enrolled, and 29 vocally healthy subjects (12 women and 17 men) aged between 25 and 81 years were also enrolled as a control group.

Background data

Vocal function and voice quality were evaluated by measuring perceptual, aerodynamic, and acoustic parameters. As perceptual parameters, the grade, roughness, and breathiness (B) scales from the GRBAS scale were rated. The GRBAS scale is a commonly-used perceptual rating scale of hoarseness, in which the qualities of hoarseness including overall severity (grade: G), roughness (R), breathiness (B), asthenia (A) and strain (S) are judged by a four-point scale from zero to three (zero is normal, and three is the worst quality). 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 harmonic-to-noise ratio. These parameters were measured at the University of Tokyo by using a dedicated software program made by one of the coauthors (H.I.) called "Ima-Pro". The abovementioned voice parameters were selected because they were most routinely evaluated in the clinical setting in Japan.

Patients with VFP underwent videostroboscopy either transorally with a rigid endoscope or transnasally with a flexible fiberscope. An image sequence obtained when the subject was phonating /i/ at a comfortable loudness and at a comfortable fundamental frequency was selected for evaluation. In the present study, synchronization was evaluated by a two-point scale: when synchronization is appropriate for the visual-perceptual vibratory evaluation, the subject was classified as 1; and when vocal fold vibration was not sufficiently evaluated because of synchronization failure, the subject was classified as 0.[2]

Table 1 summarizes the results of the aerodynamic and acoustic studies. Maximum phonation time, mean flow rate, period perturbation quotient, amplitude perturbation quotient, harmonic-to-noise ratio, grade, roughness, and B scales of the GRBAS scale showed significant intergroup differences. In the VFP group, the Voice Handicap Index-10 score was 18.8 ± 6.3 and the voice-related quality of life score was 21.9 ± 7.8, whereas the rate of synchronization by videostroboscopy (LS-3A, Nagashima Medical Inc.) was 45.3%. Table 2 summarizes other demographic data of the VFP group.

HSDI

A high-speed digital camera (FASTCAM-1024PCI; Photron, Tokyo, Japan) was connected to a rigid endoscope (#4450.501, Richard Wolf, Vernon Hills, IL, USA) *via* an attachment lens (f = 35 mm, Nagashima Medical Inc.). Recording was performed with illumination by a 300-W xenon light source at a frame rate of 4500 fps and at a spatial resolution of 512×400