Vocal Fold Vibration in Vocal Fold Atrophy: Quantitative Analysis With High-Speed Digital Imaging

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Summary: Introduction. Vocal fold vibrations of vocal fold atrophy (VFA), a rapidly increasing voice disorder owing to worldwide societal aging, have not been clarified by high-speed digital imaging (HSDI).

Methods. The HSDI method was performed on 46 patients (33 males and 13 females) with VFA and 20 vocally healthy subjects (8 males and 12 females), and the obtained data were quantitatively evaluated by frame-by-frame analysis, laryngotopography, single- and multi-line kymography, and glottal area waveform.

Results. Overall, patients with VFA revealed larger open quotients, larger lateral phase difference, larger integral glottal width (the average glottal width over a glottal cycle), and smaller speed index than vocally healthy subjects. Some gender difference was noted: in males, lateral phase difference was not significant; and in females, integral glottal width and speed index were not significant. Correlation study revealed moderate correlations between HSDI-derived parameters and conventional acoustic or aerodynamic parameters.

Conclusions. The combination of multiple HSDI analysis methods was effective in documenting the characteristics of vocal fold vibrations in VFA. The knowledge of general vibratory characteristics and gender difference is beneficial for the appropriate clinical care of VFA.

Key Words: Vocal fold atrophy–Presbyphonia–High-speed digital imaging–Aging–Anti-aging.

INTRODUCTION

Vocal fold atrophy (VFA) is a voice disorder resulting from the atrophied muscle and mucosa in the vocal folds.[1] These structural modifications lead to increased glottal air leakage and breathy, rough voice. Aging is considered to be the most major predisposing factor for VFA, although other risk factors have also been proposed (eg, reflux laryngitis, chronic medical conditions, and vocal abuse).[2] The VFA has increased considerably during the past two decades as a result of the worldwide societal aging, and thus, is attracting clinical attention in the world these days.[3,4]

Laryngoscopically, the vocal fold bowing, prominent vocal process, and spindle-shaped glottal gap are usually observed.[1,2] The vibratory characteristics observed with videostroboscopy include normal or decreased amplitude, either complete closure or glottal gap, normal mucosal wave, and small supraglottal area.[1,2,5,6]

The details of vocal fold vibrations in VFA, however, have not yet been documented by high-speed digital imaging (HSDI), although HSDI is considered to be the better choice than videostroboscopy.[7,8] First, HSDI is capable of observing actual vocal fold vibrations with a high frame rate, and guarantees reliable assessment of intra- and intercycle vibratory behaviors, unlike videostroboscopy that only provides reconstructed, averaged, illusory images. Second, HSDI offers wider application to clinical cases than videostroboscopy because HSDI is free from the problem with synchronization and is applicable to severe dysphonia in which videostroboscopy results in desynchronization. Third, various analysis methods for HSDI are now available, and thus HSDI provides more multifaceted information than videostroboscopy that has relatively limited choices of analysis methods. Furthermore, only little is known about the association between vibratory parameters and acoustic or aerodynamic parameters in VFA,[5] and HSDI data have not been reported on this matter. The connection between HSDI parameters and routinely evaluated vocal function parameters in VFA should be beneficial for better understanding the pathophysiological aspects of this clinical entity.

Hence, the purpose of the present study was to quantitatively elucidate the vibratory characteristics in VFA patients using HSDI, 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) and those who were diagnosed with VFA between 2006 and 2013 were included in this study. The diagnosis of VFA was based on careful history taking, acoustic and aerodynamic evaluation, and laryngostroboscopic findings: Patients with objective dysphonia on acoustic or aerodynamic studies; without signs of other laryngeal diseases such as vocal fold paralysis, vocal fold polyp, laryngeal carcinoma, vocal fold scar, or functional dysphonia; and with the prominent vocal process, bowed vocal fold, spindle-shaped or anterior glottal gap, or increased open phase during phonation

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were diagnosed as those having VFA. The diagnosis was made by three or four certified otorhinolaryngologists specializing in vocal treatment. As for sulcus vocalis, patients with a type 1 sulcus (physiological sulcus) were included in the category of VFA because type 1 sulcus is superficial and generally causes no or minimal functional vocal impairment.[9] Furthermore, type 1 sulcus is considered to be associated with aging.[9] On the other hand, patients with a type 2 sulcus (sulcus vergeture) or a type 3 sulcus (true sulcus vocalis) were excluded from this study.[9]

As a control group, vocally healthy subjects without vocal complaints, history of laryngeal disorders, or signs of laryngeal abnormality with laryngoendoscopy were recruited. As an exception, however, a small glottal gap was permitted for a control group in the present study because vocally healthy elderly population is known to demonstrate a small glottal gap frequently.[10]

All subjects were required to sign a consent form that was approved by our Institutional Review Board. A total of 46 patients with VFA (13 women and 33 men), with the age range between 60 and 91 years, and 20 vocally healthy subjects (12 women and eight men), with the age range between 65 and 81 years, were enrolled in the present study.

TABLE 1.
Clinical Data of All Participants

Parameter (Units)	Control (N = 20)	VFA (N = 46)	*t* Test
Age (yr)	73 ± 5	72 ± 7	0.513
MPT (s)	18.7 ± 6.6	16.4 ± 8.2	0.284
MFR (mL/s)	136 ± 36	210 ± 101	0.002†
AA-F_0 (Hz)	178 ± 50	179 ± 63	0.940
APQ (%)	3.2 ± 1.5	4.1 ± 2.3	0.135
PPQ (%)	0.31 ± 0.46	0.92 ± 0.61	<0.001‡
HNR (dB)	21.5 ± 3.5	12.6 ± 4.9	<0.001‡
Grade	0.80 ± 0.62	1.33 ± 0.52	<0.001‡
Roughness	0.80 ± 0.62	1.17 ± 0.44	0.006†
Breathiness	0.50 ± 0.51	0.65 ± 0.60	0.330

Abbreviations: SD, standard deviation; VFA, vocal fold atrophy; 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.
Notes: Values signify "mean ± SD." The column for *t* test shows the *P* value of Student's *t* test between control and VFA groups.
† $P < 0.01$.
‡ $P < 0.001$.

Background data

Vocal function and voice quality were evaluated by measuring aerodynamic and acoustic parameters. The 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 the fundamental frequency (AA–F_0), amplitude perturbation quotient, period perturbation quotient, and harmonic-to-noise ratio, which were measured at the University of Tokyo with a dedicated software program, as well as the subjective rating by the GRBAS scale.

Table 1 summarizes the results of aerodynamic and acoustic studies, in which mean flow rate, period perturbation quotient, harmonics-to-noise ratio, and the grade and roughness of the GRBAS scale revealed significant intergroup differences. The scores of Voice Handicap Index-10 and the voice-related quality of life were 13.7 ± 9.4 and 13.8 ± 8.9, respectively, and the rate of synchronization in VFA with videostroboscopy (LS-3A; Nagashima Medical, Inc.) was 67.3%.

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.). Recording was performed under illumination with a 300-W xenon light source at a frame rate of 4500 frames per second and a spatial resolution of 512 × 400 pixels, with an 8-bit grayscale and a recording duration of 1.86 seconds. High-speed digital images of sustained vowel phonation /i/ at a comfortable frequency with a comfortable intensity were recorded. The image sequence of stable vocal fold vibrations were selected for further analyses.

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

HSDI analysis methods

The recorded HSDIs were evaluated by frame-by-frame analysis,[11] laryngotopography (LTG),[12] single-/multi-line digital kymography (SLK and MLK, respectively),[13,14] and glottal area waveform (GAW).[15] The details of analysis by these methods are described elsewhere.[11–15]

The size parameters were normalized by the vocal fold length, labeled by "N_L-" (eg, V_L-amplitude mean). The time parameters were normalized by the glottal cycle, labeled by "N_G-" (eg, N_G-lateral phase difference). The size and time parameters were normalized by both glottal cycle and vocal fold length, labeled by "N_{GL}-" (eg, N_{GL}-lateral phase difference).[13]

In the present study, analysis was focused on selected parameters that were considered to be related with the vibratory characteristics of VFA such as amplitude, mucosal wave, lateral/longitudinal phase difference, open quotient, speed index, integral glottal width (the average glottal width over a glottal cycle),[13] maximal/minimal glottal area, glottal area difference, and glottal outlet (normalized supraglottal area).[6]

Frame-by-frame analysis was performed using an assessment form for HSDI developed by the authors, with which vibratory parameters such as symmetry, periodicity, amplitude, mucosal wave, phase difference, glottal closure, and supraglottal hyperactivity were evaluated by two- or four-point scale.[11] For glottal gaps, the incidence (present or absent) and glottal type (incomplete closure, posterior, spindle-shaped, or anterior) were evaluated.

The LTG is a method using a pixel-wise Fourier transform of time-varying brightness curve for each pixel across images and