Quantification of Vocal Fold Vibration in Various Laryngeal Disorders Using High-Speed Digital Imaging

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Summary: Objective. To quantify vibratory characteristics of various laryngeal disorders seen by high-speed digital imaging (HSDI).

Methods. HSDI was performed on 78 patients with various laryngeal disorders (20 with polyp, 16 with carcinoma, 13 with leukoplakia, 6 with vocal fold nodule, and 33 with others) and 29 vocally healthy subjects. Obtained data were quantitatively evaluated by frame-by-frame analysis, laryngotopography, digital kymography, and glottal area waveform.

Results. Overall, patients with laryngeal pathologies showed greater asymmetry in amplitude, mucosal wave and phase, smaller mucosal wave, and poorer glottal closure than vocally healthy subjects. Furthermore, disease-specific vibratory disturbances that generally agreed with the findings in the literature were quantified: comparing polyp with nodule, differences were noted in longitudinal phase difference, amplitude, and mucosal wave. In comparison with leukoplakia and cancer, nonvibrating area was more frequently noted in cancer.

Conclusions. The HSDI analysis of various voice disorders using multiple methods can help phonosurgeons to properly diagnose various laryngeal pathologies and to estimate the degree of their vocal disturbances.

Key Words: Vocal fold polyp–Vocal fold nodule–Laryngeal leukoplakia–Laryngeal cancer–Reinke edema–Laryngeal granuloma–Laryngeal papilloma–Vocal fold cyst–High-speed digital imaging.

INTRODUCTION

Direct observation and objective assessment of vocal fold vibration are essential for reaching an appropriate diagnosis and determining the best therapeutic approach to various voice disorders. For this purpose, videostroboscopy is used most frequently because it provides full color images with high spatial resolution at a relatively low cost. However, videostroboscopy can only be applied to the assessment of stable and periodic vocal fold vibration, whereas high-speed digital imaging (HSDI) is a superior method for assessing irregular or aperiodic vocal fold vibration that is commonly associated with voice pathology.[1–3] Quantification of oscillatory characteristics is also essential to enhance the objectivity and validity of assessment, and HSDI is superior to videostroboscopy with regard to quantification of data because it allows the registration of true intracycle or intercycle vibratory behavior and offers a wider variety of analytical methods.[1–3]

Until recently, HSDI studies of voice disorders had been conducted in a small number of patients for each voice disorder.[4–15] Only in the past few years, several HSDI studies have been published that differentiate voice disorders and quantify their oscillatory characteristics.[16–22] However, the HSDI parameters reported in these reports have been focused on temporal aspects or left-right asymmetry, and size parameters that are routinely investigated by stroboscopic examination (such as amplitude and mucosal wave) have not been fully explored. Furthermore, HSDI research has been focused on vocal fold polyps and nodules, and there is a paucity of knowledge regarding other voice disorders. Additionally, the association between HSDI-derived vibratory parameters and conventional aerodynamic or acoustic parameters in patients with voice disorders has not fully been investigated. Making a connection between HSDI parameters and common vocal function parameters should be beneficial for improving our understanding of the pathophysiological aspects of various clinical entities.

Accordingly, the purpose of the present study was to quantitatively elucidate the vibratory characteristics of various vocal fold disorders by using multiple HSDI analytical methods, including an assessment form, single-line and multiline digital kymography (SLK and MLK, respectively), laryngotopography (LTG), and glottal area waveform (GAW) analysis. In addition, the aim was to clarify the relationship between HSDI parameters and perceptual/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 were included in this study. In each patient, the diagnosis was based on a detailed history, acoustic and aerodynamic evaluation, videostroboscopy, and histologic examination and was made by agreement among three or four certified otorhinolaryngologists specializing in vocal treatment. Patients with vocal fold polyp, laryngeal carcinoma, laryngeal leukoplakia,

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laryngeal papillomatosis, laryngeal granuloma, vocal fold nodule, Reinke edema, or vocal fold cyst were included in this study. As a control group, healthy subjects were recruited who had no vocal complaints, no history of laryngeal disorders, and no signs of laryngeal abnormality on laryngoendoscopy. All subjects signed a consent form that was approved by our institutional review board.

A total of 78 patients (23 women and 55 men) aged between 22 and 87 years with various laryngeal pathologies were enrolled along with 29 vocally healthy subjects (12 women and 17 men) aged between 21 and 81 years. Twenty patients had vocal fold polyps, 16 patients had laryngeal carcinoma, and 13 patients had laryngeal leukoplakia. In addition, there were eight patients with laryngeal papillomatosis, eight with laryngeal granuloma, six with vocal fold nodule, five with Reinke edema, and four with vocal fold cyst.

Background data

Vocal function and voice quality were evaluated by measuring aerodynamic and acoustic parameters. 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, including the fundamental frequency (AA-F_0), amplitude perturbation quotient, period perturbation quotient, and harmonics-to-noise ratio, were measured at the University of Tokyo with a dedicated software program. Perceptual voice ratings were also determined by using the GRBAS scale.

Table 1 summarizes the results of perceptual, aerodynamic, and acoustic studies. The maximum phonation time, mean flow rate, period perturbation quotient, and harmonics-to-noise ratio, as well as the grade, roughness, and breathiness on the GRBAS scale, showed significant intergroup differences. The Voice Handicap Index-10 and voice-related quality of life scores were 10.8 ± 7.3 and 14.3 ± 10.8, respectively, and the rate of synchronization of videostroboscopy (LS-3A, Nagashima Medical Inc., Tokyo, Japan) was achieved in 60.6% of the patients.

High-speed digital imaging

For HSDI, a high-speed digital camera (FASTCAM-1024PCI; Photron, Tokyo, Japan) was connected to a rigid endoscope (#4450.501, Richard Wolf, Vernon Hills, Illinois, USA) via an attachment lens ($f = 35$ mm, Nagashima Medical Inc., Tokyo, Japan). Illumination was provided by a 300-W xenon light source, and recording was performed at a frame rate of 4500 fps 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 were recorded during sustained phonation of the vowel /i/ at a comfortable frequency and comfortable intensity. Then, an image sequence with stable vocal fold vibrations was selected for further 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 HSDI parameters and perceptual/aerodynamic/acoustic parameters.

HSDI analysis

The recorded HSDI data were evaluated by frame-by-frame analysis,[23] LTG,[24] SLK and MLK,[25,26] and GAW analysis.[27] The details of these methods have been described elsewhere.[23–27]

Size parameters normalized by the vocal fold length were signified by the term "N_L-" (eg, N_L-amplitude mean), whereas time parameters normalized by the glottal cycle were signified by "N_G-" (eg, N_G-lateral phase difference). In addition, size and time parameters normalized by both the glottal cycle and vocal fold length were signified by "N_{GL}-" (eg, N_{GL}-lateral phase difference).[25]

TABLE 1.
Clinical Data of All Participants Are Summarized

Parameter (U)	Control Group (n = 29)	Pathologic Group (n = 78)	*P* Value
Age (y)	59 ± 21	59 ± 16	0.973
Gender (n)	Male (17), female (12)	Male (55), female (23)	0.248
MPT (s)	22.3 ± 9.7	15.9 ± 8.1	0.002**
MFR (mL/s)	135 ± 37	220 ± 80	<0.001***
AA-F_0 (Hz)	160 ± 51	175 ± 46	0.232
APQ (%)	2.8 ± 1.5	3.6 ± 1.8	0.066
PPQ (%)	0.26 ± 0.39	0.74 ± 0.84	<0.001***
HNR (dB)	22.1 ± 3.9	14.5 ± 4.8	<0.001***
Grade	0.62 ± 0.62	1.48 ± 0.57	<0.001***
Roughness	0.62 ± 0.62	1.48 ± 0.57	<0.001***
Breathiness	0.38 ± 0.49	0.71 ± 0.65	<0.002**

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.

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 various vocal fold pathology groups.

$^{**}P < 0.01$; $^{***}P < 0.001$.