Age- and Gender-Related Difference of Vocal Fold Vibration and Glottal Configuration in Normal Speakers: Analysis With Glottal Area Waveform

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Summary: Introduction. Glottal area waveform (GAW) analysis is widely used in the assessment of vocal fold vibration by high-speed digital imaging (HSDI). Because normative GAW data obtained from a large number of subjects have not been reported, we conducted a prospective study to obtain normative results for GAW analysis of HSDI findings and clarify normal variations associated with gender and age.

Methods. Vocally healthy adults were divided into a young group (aged $\leq$ 35 years) and an elderly group (aged $\geq$ 65 years). The configuration and size of the glottal area were assessed at different phases of the glottal cycle, and gender- and age-related differences were evaluated.

Results. A total of 26 young subjects (nine men and 17 women; mean age: 27 years) and 20 elderly subjects (eight men and 12 women; mean age: 73 years) were investigated. The glottal area at different points of the glottal cycle showed a negative correlation with frequency. Although the GAW parameters of young women appeared to be different from those of the other subgroups, the differences were not statistically significant. Young women predominantly had a triangular- or vase-shaped glottal configuration at all frequencies, whereas the other subgroups showed various glottal shapes.

Conclusion. The present study clarified gender- and age-related differences of GAW parameters obtained with HSDI. Young women were likely to show different glottal configurations and different responses to frequency changes from those of young men, elderly men, and elderly women. Phonosurgeons should pay attention to the normal variations detected in the present study.

Key Words: Voice–Normal–High-speed digital imaging–Glottal area waveform.

INTRODUCTION

High-speed digital imaging (HSDI) is currently regarded as a superior method to videostroboscopy for the assessment of vocal fold vibrations.[1–3] First, HSDI is applicable to the assessment of unstable phonations such as transient, subharmonic, or aperiodic phonations and thus is more useful for investigating vocal pathology than videostroboscopy. Second, HSDI can visualize real-time vocal fold vibrations, which provides greater validity for assessment of intracycle and intercycle vibratory characteristics compared with videostroboscopy, in which the images are reconstructed and illusory.[3–9] Third, HSDI data can be analyzed by a wider variety of methods than videostroboscopy data, enabling more interpretable and extensive evaluation on both a qualitative and quantitative basis.[10–15]

Recently, *multiline kymography*, *laryngotopography*, and *phonovibrography* have been widely used for analysis of HSDI data.[10–15] These methods, however, have limitations in the assessment of overall glottal area dynamics, which is an essential element in the understanding of vocal fold vibration—although *multiline kymography*, which displays vocal fold movements at several horizontal lines over a selected period in a single image, is effective for assessing the temporal aspects of vocal fold vibrations such as periodicity, it has limitation in the assessment of longitudinal information[10–12]; *laryngotopography* uses pixel-wise Fourier transformation of a time-varying brightness curve for each pixel across images and allows intuitive quantitative assessment of the spatial features of vocal fold vibrations but lacks temporal information[10,11,13,14]; and *phonovibrography* provides information on the velocity and acceleration of vocal fold vibrations and is especially useful for assessing dynamics in the anterior-posterior direction, but mediolateral evaluation is complicated with this technique.[15]

For the analysis of the general dynamics of the glottal area, *glottal area waveform* (GAW), which automatically traces the vocal fold edges and displays temporal changes of the glottal area, is considered to be sufficient.[16] The concept of GAW analysis was first introduced by Timcke et al[17,18] in the 1950s with high-speed cinematography, and normal GAW data of approximately 10 subjects were provided in their series of GAW studies. The application of GAW has been extended to videostroboscopy during the past decade, and Woo[19] obtained normative data in 60 young subjects and described gender differences with videostroboscopy in 1996. Basic GAW parameters were introduced by

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Timcke et al[17,18] and later, Woo[19] introduced *OT-50* using videostroboscopy, after which Noordzu and Woo[20] applied these parameters to patients with various laryngeal diseases. Recently, Omori et al[21,22] measured the normalized amplitude, and Bloch and Behrman[23] measured the supraglottal area using videostroboscopy.

However, there exist several drawbacks regarding GAW. GAW parameters in a number of normophonic subjects have not been obtained with HSDI. Normal GAW values via HSDI are needed to validate previous GAW studies because HSDI can demonstrate true intracycle vibratory patterns, whereas videostroboscopy only produces illusory vibratory images that might not reflect the actual intracycle characteristics. In addition, age- or gender-related differences of GAW parameters using HSDI have not been clarified, either. Woo[19] did report significant differences in speaking fundamental frequency (F_0), minimal glottal area, maximal glottal area, opening phase, and closing phase between normal young men and women. However, this study did not refer to the spatial vibratory or geographic differences between these two groups, which were observed in the authors' previous HSDI studies: young women frequently show a posterior glottal gap and a posterior-to-anterior opening pattern, whereas young men frequently show supraglottic hyperactivity, complete glottal closure, and anterior-to-posterior opening.[12,14,24] Although these geographic characteristics of glottal area have not been investigated in the previous GAW studies, they are relevant to the judgment of normality and abnormality or the diagnosis of voice disorder: for instance, because young women frequently show a posterior glottal gap,[12,14,24] an anterior glottal gap seen in a young women is likely to be abnormal findings; and a spindle-shaped glottal gap is likely to be observed in vocal fold atrophy or sulcus vocalis,[25] whereas incomplete glottal closure is likely to be associated with vocal fold paralysis.[10,11] Furthermore, although Omori et al[21,22] reported significant correlations between limited GAW parameters and acoustic/aerodynamic parameters using videostroboscopy, correlations between GAW parameters obtained with HSDI and acoustic/aerodynamic parameters were not systemically assessed. Connecting GAW parameters and physiological parameters should improve the interpretation of vocal fold vibrations by this method and should allow us to single out key items from a number of existent GAW parameters.

Accordingly, the aim of the present study was to provide normative vibratory and geographic GAW data using HSDI to clarify gender- and age-related differences regarding GAW parameters and connect GAW parameters to the widely used aerodynamic/acoustic parameters.

MATERIALS AND METHODS

Subjects

Vocally healthy volunteers with no vocal symptoms and no history of laryngeal disease were recruited to participate in the present study and were divided into a young group (aged 21–35 years) and an elderly group (aged ≥65 years). All subjects were required to sign a consent form that was approved by our Institutional Review Board. A total of 46 subjects (29 women and 17 men) were enrolled, including 26 subjects (nine men and 17 women) in the young group and 20 subjects (eight men and 12 women) in the elderly group. Table 1 includes the demographic data of all the subjects in this study.

Aerodynamic and acoustic parameters

Vocal function and voice quality were evaluated by measuring aerodynamic and acoustic parameters. The aerodynamic parameters included the maximum phonation time, mean flow rate, and laryngeal resistance measured by the Nagashima PE-77E Phonatory Function Analyzer (Nagashima Medical Inc., Tokyo, Japan). Acoustic variables, including the F_0, amplitude perturbation quotient, period perturbation quotient, and harmonics-to-noise ratio, were measured with a dedicated software program at the University of Tokyo. These parameters were selected because they are most commonly evaluated in the clinical routine at Japanese voice centers.

Table 1 lists the aerodynamic parameters and acoustic parameters of all the subjects in this study along with normal values for Japanese subjects (except for the harmonics-to-noise ratio that was not found in the literature).[26,27]

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 fps and a spatial resolution of 512 × 400 pixels, with an 8-bit grayscale and a sampling time of 1.86 seconds. High-speed digital images were recorded during sustained phonation of the vowel /i/ with a comfortable intensity at a low frequency, a speaking F_0, and a high frequency. For the recording of a speaking F_0, subjects were asked to phonate at a comfortable frequency of a modal register, whereas low/high-frequency phonations were recorded by asking subjects to phonate as low/high as they could within a modal register. The vowel /i/ was selected for phonation to obtain good glottal exposure while using a rigid endoscope.

Aerodynamic and acoustic studies were performed approximately 30 minutes before the HSDI study 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 GAW parameters and aerodynamic/acoustic parameters.

GAW analysis

GAW analysis of the recorded high-speed digital images was performed as follows. After selecting a segment with good focus, brightness, and contrast by visual inspection, the following GAW parameters were measured. (1) The GAW parameters commonly examined in the previous GAW studies: vocal fold length (*VFL*), minimum glottal area (*min-GA*), maximum glottal area (*max-GA*), and glottal outlet (*GOL*). (2) The newly introduced GAW parameters that should help understand the intracycle characteristics: glottal area at the