Chapter 2
HSDI of the vocal fold vibrations in healthy young & elderly males and females

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Abstract

Observation of vocal fold (VF) behavior in young females showed posterior gap and posterior-to-anterior longitudinal phase difference while in young males mucosal wave, anterior-to-posterior longitudinal phase difference, and supraglottic hyperactivity were frequent. In elderly females high incidence of lateral phase difference, atrophic change, anterior gap, and asymmetry were observed. In elderly males axis shift, asymmetry, supraglottic hyperactivity, increased mucosal wave, lateral phase difference, and anterior-to-posterior longitudinal phase difference were frequent. VF vibrations are diverse even in healthy subjects, and hence, this diversity must be taken into account in evaluating VF vibrations.

Keywords: *HSDP, age, gender, VF vibrations, asymmetry, wave characteristics*

Introduction

To observe unstable vocal fold (VF) vibrations in health and in disease, high-speed digital imaging (HSDI) is considered to be a tool of choice [1-11]. To overcome difficulties in processing HSDI, various quantitative analysis (glottal area waveform, kymography, and phonovibrography) have been proposed [8-11]. In videostroboscopy, comprehensive assessment forms are widely used in clinical situations and its clinical effectiveness has been reported [12]. There is, however, no comprehensive assessment form for HSDI. Hence, it is desirable to establish a comprehensive assessment form for HSDI. Another problem with HSDI is a relative scarcity of normative data which is indispensable for discrimination between normal and pathological VF vibrations [4, 13-18]. Lack of these data are specifically acute with regard to normal elderly people [4, 13-18]. The data are crucial in handling voice complaints of the ever enlarging geriatric population. Hence, we developed here a comprehensive assessment form for HSDI with the goal to provide normative data on VF vibration in both young and elderly populations.

Methods

Subjects

Volunteered subjects (males and females) who were vocally healthy participated in the present study, and were divided into young (aged from 21 to 35 years) and elderly groups (aged 65 years and more). All subjects were required to complete an Institution-Review-Board-approved consent form. A total of 46 subjects (29 women, 17 men) participated in our study: 26 subjects (9 men, 17 women) for the young group and 20 subjects (8 men, 12 women) for the elderly group.

Aerodynamic studies and acoustic analysis

Prior to HSDI, vocal function and voice quality were evaluated with aerodynamic and acoustic measures. Aerodynamic measures included the maximum phonation time (MPT), mean flow rate and laryngeal resistance measured by the Nagashima PS-77E Phonatory Function Analyzer® (Nagashima Medical Instrument Corporation, Tokyo, Japan), and the maximum phonation time [19]. Acoustic characteristics such as the fundamental frequency, shimmer, jitter, and harmonics-to-noise ratio were measured by dedicated software developed by our research group. Voice quality was scored using the GRBAS scale by subjective listening tests performed by several otolaryngologists.

HSDI

The high-speed digital camera, Photron FASTCAM-1024PCI, connected to a rigid endoscope (#4450.501, Richard Wolf) via an attachment lens (f = 35 mm, Nagashima Medical Instrument Corporation), was used to obtain laryngeal images. Recordings were taken with a 300-W Xenon light source illumination at a frame speed of 4500 f/s with a spatial resolution of 512 x 400 pixels, 8-bit grayscale, and with a maximum recording duration of 1.88 s.

Laryngeal images were acquired for the following vocal tasks: sustained phonation at a speaking fundamental frequency, a low frequency, and a high frequency. For a speaking fundamental frequency, subjects were asked to sustain /i/ at a comfortable frequency and intensity; for a high-pitch and low-pitch phonation, subjects were asked to phonate at higher or lower pitch than a speaking fundamental frequency in modal register. Effort was made to capture all images in the middle of phonation, not at the beginning or at the end of phonation, and only a single segment was obtained and processed from each individual.

Rating form for HSDI

HSDI assessment form (Figure 1) was based on an existing assessment form for videostroboscopy [4, 11, 13-18] and contained following perceptive features: symmetry, periodicity, glottal closure, glottal gap, closed phase, supraglottic hyperactivity, secretion, atrophic change, edematous change, non-vibrating area, amplitude, mucosal wave, longitudinal phase difference, lateral phase difference, and axis shift. Glottal gap was evaluated as to size and location. Amplitude and mucosal wave were evaluated as to magnitude and left-right difference.

All categories were rated with a four-point scale except for glottal closure (0: complete closure, 1: incomplete closure, and 2: no closure), periodicity (0: periodic and 1: aperiodic) and non-vibrating area (0: absent and 1: present). Glottic gap location was subdivided into anterior, mid-glottal, or posterior types; incomplete closure was categorized into posterior gap. Longitudinal phase difference was further subdivided into posterior-to-anterior and anterior-to-posterior opening types. The posterior-to-anterior opening was defined as positive longitudinal phase difference and vice versa, since the posterior-to-anterior opening type was considered to be a normal phenomenon rather than the anterior-to-posterior opening type. Axis shift is the transition of approximated VF edges in the left-right direction during closed phase [9].

Image analysis was performed by three larynogologists who were familiar with videolaryngostroboscopic examination. From the HSDI films, the segment with good exposure of the glottis, illumination, and contrast was selected by visual inspection. After a training session with exemplary HSDI films, assessment was performed twice, one week apart. The order of HSDI films was randomized. For each category, the most frequent value of three raters was selected. Inter- and intra-rater reliabilities were calculated from the data as well.

Categories		Rating			
Symmetry		0 Symmetry	1 Slight Asymmetry	2 Moderate Asymmetry	3 Severe Symmetry
Periodicity		0 Periodic	1 Aperiodic		
Glottal Closure		0 Incomplete or No Closure	1 Short	2 Normal	3 Long
Glottal Gap	Size	0 No Gap	1 Small Gap	2 Moderate Gap	3 Large Gap
	Location		1 Anterior	2 Mid-glottal	3 Posterior
Mucosal Wave	Right	0 Absent	1 Diminished	2 Normal	3 Enlarged
	Left	0 Absent	1 Diminished	2 Normal	3 Enlarged
	Left-Right Difference	0 Absent	1 Slight	2 Moderate	3 Great
Amplitude	Right	0 Absent	1 Diminished	2 Normal	3 Enlarged
	Left	0 Absent	1 Diminished	2 Normal	3 Enlarged
	Left-Right Difference	0 Absent	1 Slight	2 Moderate	3 Great
Lateral Phase Difference	Left-to-Right	0 Absent	1 Slight	2 Moderate	3 Great
	Right-to-Left	0 Absent	1 Slight	2 Moderate	3 Great
Longitudinal Phase Difference	Anterior-to-Posterior	0 Absent	1 Slight	2 Moderate	3 Great
	Posterior-to-Anterior	0 Absent	1 Slight	2 Moderate	3 Great
Axis Shift	Leftward	0 Absent	1 Slight	2 Moderate	3 Great
	Rightward	0 Absent	1 Slight	2 Moderate	3 Great
Supraglottic Hyperactivity		0 Absent	1 Slight	2 Moderate	3 Great
Secretion		0 Absent	1 Slight	2 Moderate	3 Great
Atrophic Change		0 Absent	1 Slight	2 Moderate	3 Great
Edematous Change		0 Absent	1 Slight	2 Moderate	3 Great
Non-vibrating Area		0 Absent	1 Present		

Figure 1. An assessment form for high-speed digital imaging.

Statistical analysis

For normally distributed numerical data, two-tailed Student's t tests were used; for non-normally distributed numerical data or categorical data, Mann-Whitney's U tests were applied. Comparisons between subgroups were performed by analysis of variance (ANOVA) and parameters with significant differences were further assessed by Scheffe's F-tests. Pearson or Spearman Correlation was used to determine relationship between HSDI findings and aerodynamic and acoustic measures. Difference with $P<0.05$ was considered significant.

Results

Demographics, acoustic and aerodynamic parameters

Table 1 lists demographic data, aerodynamic function parameters, and acoustic parameters of all subjects along with normal values in Japanese subjects except for harmonics-to-noise ratio [20-22].

Assessment form of high-speed digital imaging

Characteristics of HSDI parameters with the comparison among subgroups in a speaking fundamental frequency are shown in Figure 2. Both inter-rater and intra-rater reliability ranged from 75-100%.

Symmetry

In a speaking fundamental frequency, 39%, 39%, and 22% of all subjects were rated as symmetrical, slightly asymmetrical, and moderately asymmetrical, respectively. Asymmetry revealed no significant differences among pitches (P=0.31) or subgroups (P=0.79), although it was relatively more frequent (75%) and severer in elderly males compared with other subgroups in a speaking fundamental frequency.

Periodicity

In all subjects, VF vibrations were periodic and there were no significant differences among pitches (P=1.00) or subgroups (P=1.00).

Glottal Closure and Glottal Gap

In a speaking fundamental frequency, glottal closure was complete in 62%, incomplete in 9%, and partial due to glottal gap in 30%. With incomplete closure included into posterior gap, glottal gaps were posteriorly located in 72% and anteriorly located in 28% (no mid-glottal gap). The occurrence of incomplete closure and glottal gap were positively correlated with pitch (P<0.01, P<0.05, respectively). The gap size was also positively correlated with the pitch increase (P<0.01). In a speaking fundamental frequency, glottal gap was frequent in young females (53%) and elderly females (50%), and infrequent in young males (22%) and elderly males (13%), although the differences among subgroups were insignificant (P=0.15). In young females, all the glottal gaps were posteriorly located while in elderly females 80% of glottal gaps were anteriorly located.

Closed Phase

Closed phase was assessed as short in 20%, normal in 76%, and long in 4% of all subjects at a speaking fundamental frequency. Closed phase significantly shortened when the pitch increased (P<0.01). The differences among subgroups were insignificant (P=0.12).

Mean Amplitude and Amplitude Difference

Mean amplitude was rated to be small in 38%, normal in 55%, and large in 7%; left-right amplitude difference was absent in 78% and slightly noted in 22% of all subjects at a speaking fundamental frequency. Mean amplitude significantly decreased as pitch increased (P<0.01) while amplitude difference revealed no correlation with pitch (P= 0.10). No significant differences in mean amplitude (P=0.35) and amplitude difference (P=0.25) among subgroups was observed.

Table 1. Demographic data, and acoustic and acoustic parameters of each subgroup.

		Women					Men							
Subgroup (n)		Young	(n = 17)	Elderly	(n = 12)		Young	(n = 9)	Elderly	(n = 8)				
Parameter	Normal Value: Mean±SD (Range) (Reference)	Mean±SD	Range	Mean±SD	Range	P value (YF vs EF)	Mean±SD	Range	Mean±SD	Range	P value (YM vs EM)	P value (YF vs YM)	P value (EF vs EM)	P value (all subjects)
Age		26±3	21-32	73±5	65-80		29±3	25-33	74±4	67-81				
MPT (s)	Women, 20.3 (14.2-27.6); Men, 29.7 (21.2-39.7) (20)	23.7±7.0	12.6-35.4	17.1±4.8	11.3-25.5	<0.01**	30.5±10.9	16.0-45.5	21.0±8.5	10.6-33.1	0.07	0.07	0.21	<0.01**
MFR (ml/s)	Women, 102.0±36.0; Men, 120.0±41.0 (20)	127.9±39.2	92.2-371.3	126.5±30.6	81.3-229.9	0.92	131.8±41.5	106.3-216.4	150.6±40.0	114.3-333.2	0.36	0.82	0.14	0.50
F0 (Hz)	Women, 251.5±24.4; Men, 132.0±19.7 (21)	236.3±23.2	195.4-274.6	204.5±45.5	127.9-295.4	0.02*	119.1±17.0	90.7-143.0	138.6±24.4	109.9-187.7	0.07	<0.01**	<0.01**	<0.01**
APQ (%)	Women, 2.07±0.68; Men, 2.19±0.72 (21)	2.68±1.36	1.16-5.90	3.29±1.71	1.17-6.30	0.31	1.80±0.91	1.03-3.75	3.08±1.20	1.37-4.49	0.03*	0.10	0.77	0.10
PPQ (%)	Women, 0.47±0.32; Men, 0.31±0.14 (21)	0.28±0.19	0.10-0.89	0.39±0.60	0.09-2.21	0.51	0.16±0.07	0.10-0.29	0.19±0.11	0.09-0.37	0.49	0.08	0.37	0.42
HNR (dB)	Women, 18.8±1.0; Men, 18.4±0.6 (22)	23.8±3.9	16.4-30.1	21.7±3.7	17.6-29.7	0.15	23.5±4.7	14.5-28.4	21.2±3.4	17.6-25.9	0.28	0.83	0.77	0.32
		Mode	25%Q-Median-75%Q	Mode	25%Q-Median-75%Q	P value (YF vs EF)	Mode	25%Q-Median-75%Q	Mode	25%Q-Median-75%Q	P value (YM vs EM)	P value (YF vs YM)	P value (EF vs EM)	P value (all subjects)
The GRBAS scale														
Grade	(0-1) (20)	1	0-1-1	1	0-1-1	0.57	0	0-0-0	1	0.5-1-1	0.03*	0.02*	0.78	0.07
Roughness	(0-1) (20)	1	0-1-1	1	0-1-1	0.57	0	0-0-0	1	0.5-1-1	0.03*	0.02*	0.78	0.07
Breathiness	0 (20)	0	0-0-0	0	0-0.5-1	0.07	0	0-0-0	1	0-0.5-1	0.09	0.68	1.00	0.09
Asthenia	0 (20)	0	0-0-0	0	0-0-0	1.00	0	0-0-0	0	0-0-0	1.00	1.00	1.00	1.00
Strain	(0-0.5) (20)	0	0-0-0	0	0-0-0	0.24	0	0-0-0	0	0-0-0.5	0.13	1.00	0.33	0.10

MPT = maximum phonation time; MFR = mean flow rate; F0 = fundamental frequency; APQ = amplitude perturbation quotient; PPQ = period perturbation quotient; HNR = harmonics-to-noise ratio; SD = standard deviation; YF = young female; EF = elderly female; YM = young male; EM = elderly male; Q = quartile; * = P<0.05; ** = P<0.01

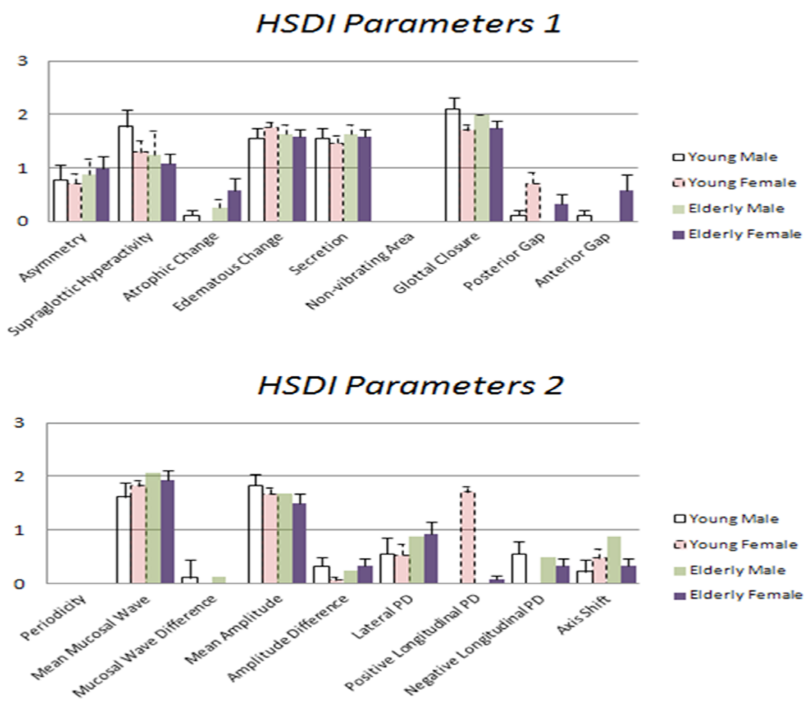

Figure 2. Graphs of each high-speed digital imaging parameter. X-axis lists each parameter and y-axis is the rating of each parameter. The bar and beard signify 50%- and 75%-quartile, respectively.

Mean Mucosal Wave and Mucosal Wave Difference

Mean mucosal wave was rated as small in 28%, normal in 59%, and large in 13%; left-right mucosal wave difference was absent in 92% and noted slightly in 8% of all subjects at a speaking fundamental frequency. Mean mucosal wave significantly decreased as the pitch increased ($P<0.01$) while there was no correlation between mucosal wave difference and pitch ($P=0.38$). There were no age- or gender-related differences in mean mucosal wave ($P=0.19$) and mucosal wave difference ($P=0.33$).

Longitudinal Phase Difference

Longitudinal phase difference was noted in 65% of all subjects at a speaking fundamental frequency, of which 60% was posterior-to-anterior and 40% was anterior-to-posterior opening type. The incidence and magnitude of longitudinal phase difference negatively correlated with pitch ($P<0.01$). In a speaking fundamental frequency, longitudinal phase difference was noted in 44%, 100%, 50%, and 42% of young males, young females, elderly males, and elderly females, respectively ($P<0.01$).

Posterior-to-anterior longitudinal phase difference was almost exclusively found in young females (100% in a speaking fundamental frequency). The occurrence decreased as the pitch increased although the difference was insignificant ($P=0.49$) and the magnitude was negatively correlated with the pitch ($P<0.01$). Anterior-to-posterior longitudinal phase difference was relatively frequent in young males (44% in a speaking fundamental frequency). The occurrence decreased according to the pitch rise although the difference was insignificant ($P=0.13$) and the magnitude was negatively correlated with pitch ($P<0.01$).

Lateral Phase Difference and Axis Shift

Lateral phase difference was absent in 57%, slight in 17%, and moderate in 26%. There were no significant differences in terms of pitch (P=0.89) or subgroups (P=0.59), although it tended to be more frequent and severer in elderly subjects.

Axis shift was absent in 67%, slight in 20%, and moderate in 13% of all subjects in a speaking fundamental frequency (P<0.01). The incidence of axis shift was negatively correlated with pitch (P=0.02). Although differences were not significant (P=0.27), elderly males tended to manifest severer axis shift than other subgroups.

Other findings

Supraglottic hyperactivity was absent in 20%, slight in 13%, moderate in 24%, and severe in 13%. It was negatively correlated with pitch (P<0.01). Supraglottic hyperactivity was more conspicuous in young males (89%), although there was no significant difference among subgroups (P=0.41).

Secretion was absent in 2%, slight in 41%, and moderate in 57% in a speaking fundamental frequency. There were no significant changes associated with pitch (P=0.06) or no differences among subgroups (P=0.91).

Edematous change was rated as slight in 29% and moderate in 71% in a speaking fundamental frequency. Edematous change was rated as milder as the pitch increased (P<0.01) while there was no significant difference among subgroups (P=0.68).

Atrophic change was absent in 83%, slight in 13%, and moderate in 4% in a speaking fundamental frequency. Although there was no significant change according to the pitch, it was significantly different among subgroups (P=0.02) and tended to be more frequent and severer in elderly females.

Non-vibrating area was not noted in all subjects.

Summary of characteristics of each subgroup

Posterior gap and posterior-to-anterior longitudinal phase difference was characteristic to young females. Young males tended to manifest decreased mucosal wave, anterior-to-posterior longitudinal phase difference, and supraglottic hyperactivity. In elderly males, axis shift, asymmetry, supraglottic hyperactivity, increased mucosal wave, lateral phase difference, and anterior-to-posterior longitudinal phase difference was frequent. Elderly females revealed a high incidence of lateral phase difference, atrophic change, and anterior gap.

Correlations between HSDI findings and other objective measures

Table 2a and 2b list correlations between HSDI features and selected aerodynamic and acoustic parameters. Fundamental frequency was positively correlated with posterior-to-anterior longitudinal phase difference and posterior gap, and negatively correlated with glottal closure, amplitude difference, mucosal wave difference, and anterior-to-posterior longitudinal phase difference. Flow rate on easy phonation was positively correlated with amplitude difference and anterior-to-posterior longitudinal phase difference. There was a weak positive correlation between subglottal pressure on easy phonation and posterior-to-anterior longitudinal phase difference, axis shift and the maximum phonation time, amplitude and the mean flow rate, mucosal wave difference and the B scale, and atrophic change and the S scale. Intensity on easy phonation was negatively correlated with posterior-to-anterior longitudinal phase difference.

Table 2a. Correlations between high-speed digital imaging characteristics and acoustic parameters calculated by the Spearman correlation.

	Aerodynamic Parameters					
Parameter	MPT	MFR	Laryngeal Resistance (Easy Phonation)	Intensity (Easy Phonation)	Subglottal Pressure (Easy Phonation)	Flow Rate (Easy Phonation)
Assymetry	-0.08	0.11	-0.14	0.04	-0.12	0.03
Glottal closure	0.17	-0.17	-0.05	0.14	0.13	0.10
Glottal gap	-0.20	0.09	-0.06	-0.23	0.00	0.01
Anterior gap	-0.14	-0.17	0.08	-0.08	-0.24	-0.08
Posterior gap	-0.10	0.21	-0.14	-0.20	0.19	0.06
Supraglottic hyperactivity	0.10	-0.13	0.05	-0.02	0.14	-0.08
Secretion	0.02	-0.04	-0.27	0.11	0.10	0.06
Atrophic change	-0.24	-0.02	-0.01	0.07	-0.29	0.04
Edematous change	0.04	-0.08	0.08	-0.21	-0.04	-0.13
Nonvibrating area	N/A	N/A	N/A	N/A	N/A	N/A
Periodicity	N/A	N/A	N/A	N/A	N/A	N/A
Mean amplitude	-0.05	0.25	0.05	-0.23	-0.02	0.14
Right amplitude	0.08	0.32*	0.08	-0.13	-0.13	0.20
Left amplitude	0.00	0.13	0.11	-0.25	0.10	0.06
Amplitude difference	-0.12	0.11	0.06	0.07	-0.08	0.31*
Mean mucosal wave	-0.20	0.12	0.01	0.06	-0.01	-0.07
Right mucosal wave	-0.18	0.12	0.20	0.10	0.02	-0.08
Left mucosal wave	-0.18	0.07	0.20	0.01	-0.05	-0.12
Mucosal wave difference	-0.17	0.07	-0.34*	0.02	0.09	0.22
Longitudinal phase difference	0.08	-0.05	0.04	-0.36*	0.31*	-0.05
A-to-P longitudinal phase difference	-0.08	0.05	0.00	0.16	-0.13	0.31*
P-to-A longitudinal phase difference	0.11	-0.08	0.03	-0.40**	0.36*	-0.24
Lateral phase difference	-0.01	-0.12	0.04	0.17	-0.06	-0.02
L-to-R lateral phase difference	0.13	-0.13	0.08	0.17	0.08	-0.09
R-to-L lateral phase difference	-0.20	-0.02	-0.08	0.06	-0.11	0.03
Axis shift	0.30*	-0.23	0.11	0.18	-0.12	-0.07
Leftward axis shift	0.22	-0.18	0.12	0.23	0.03	-0.16
Rightward axis shift	0.05	-0.13	-0.11	-0.10	-0.26	-0.10

Table 2a. Correlations between high-speed digital imaging characteristics and aerodynamic parameters calculated by the Spearman correlation.

	Acoustic Parameters								
	Acoustic Analysis				GRBAS Scale				
Parameter	F0	HNR	APQ	PPQ	Grade	Roughness	Breathiness	Asthenia	Strain
Assymetry	-0.04	0.19	-0.11	-0.09	-0.16	-0.16	0.03	N/A	0.06
Glottal closure	-0.30*	0.07	-0.15	0.00	-0.05	-0.05	0.01	N/A	0.09
Glottal gap	0.37*	0.01	0.05	-0.09	0.07	0.07	-0.13	N/A	-0.05
Anterior gap	0.07	-0.19	0.19	0.01	0.09	0.09	0.16	N/A	0.15
Posterior gap	0.35*	0.13	-0.08	-0.09	0.04	0.04	-0.26	N/A	-0.16
Supraglottic hyperactivity	-0.25	0.10	-0.14	0.07	0.05	0.05	0.02	N/A	0.01
Secretion	0.05	0.03	-0.08	-0.08	-0.07	-0.07	-0.02	N/A	-0.11
Atrophic change	0.02	-0.20	-0.10	0.19	0.16	0.16	0.19	N/A	0.32*
Edematous change	0.03	-0.03	0.08	0.06	0.10	0.10	-0.01	N/A	0.01
Nonvibrating area	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Periodicity	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Mean amplitude	-0.21	-0.17	0.12	0.16	-0.09	-0.09	0.10	N/A	-0.02
Right amplitude	-0.26	-0.10	0.06	0.12	-0.13	-0.13	0.10	N/A	0.01
Left amplitude	-0.11	-0.17	0.14	0.16	0.00	0.00	0.10	N/A	-0.01
Amplitude difference	-0.31*	-0.12	-0.01	-0.13	-0.07	-0.07	0.07	N/A	0.27
Mean mucosal wave	-0.17	-0.19	0.26	0.24	0.11	0.11	0.19	N/A	0.07
Right mucosal wave	-0.13	-0.18	0.27	0.22	0.10	0.10	0.16	N/A	0.08
Left mucosal wave	-0.13	-0.20	0.25	0.25	0.10	0.10	0.16	N/A	0.08
Mucosal wave difference	-0.31*	-0.01	0.04	0.07	0.15	0.15	0.32*	N/A	-0.06
Longitudinal phase difference	0.46**	0.12	0.01	0.11	-0.02	-0.02	-0.24	N/A	-0.09
A-to-P longitudinal phase difference	-0.33*	-0.04	-0.01	-0.26	-0.07	-0.07	0.13	N/A	0.24
P-to-A longitudinal phase difference	0.63**	0.16	0.01	0.26	0.05	0.05	-0.27	N/A	-0.21
Lateral phase difference	0.00	0.10	-0.12	-0.01	-0.22	-0.22	-0.03	N/A	0.10
L-to-R lateral phase difference	0.07	0.23	0.25	-0.17	-0.18	-0.18	-0.08	N/A	-0.03
R-to-L lateral phase difference	-0.06	-0.17	0.13	0.18	-0.12	-0.12	0.04	N/A	0.18
Axis shift	-0.06	0.08	-0.13	-0.09	-0.07	-0.07	-0.14	N/A	0.10
Leftward axis shift	-0.03	0.15	-0.20	-0.13	-0.10	-0.10	-0.19	N/A	0.01
Rightward axis shift	0.03	0.07	0.24	0.12	0.16	0.16	0.13	N/A	0.23

Discussion

The assessment form for HSDI in the current study has three benefits: 1) it is comprehensive enough to contain almost all the features evaluated in the previous HSDI studies [4, 13-18]; 2) It is easy to fill out since the completion of the form only takes a couple of minutes; and 3) it is robust since the inter- and intra-rater reliabilities were high. However, it can be extended or refined along with future studies. For instance, other scales might be selected although we adopted three- or four-point scales [13-17, 23]. The stratification of each category might also have room for discussion (e.g., gap location).

The high incidence of posterior gap and posterior-to-anterior longitudinal phase difference in young females was compatible with the past reports: posterior gap was seen in 70-100% of young females and longitudinal phase difference was seen in 70-83% of young subjects [16,24-27]. These features might result from the relatively high density of the VF of young females due to hormonal effect, and the activity of the crycothyroid and posterior crycoarytenoid muscles, which work in a high-pitch phonation and make the VF tense and slightly abducted. These two factors would lead to a strong contact of the anterior glottis and a weak or incomplete closure of the posterior glottis, thus the opening of the posterior glottis would precede the opening of the anterior glottis. Positive correlation between subglottal pressure and posterior-to-anterior longitudinal phase difference seems compatible with this speculation.

On the other hand, the high incidence of axis shift, asymmetry, and lateral phase difference of elderly males was presumably due to the asymmetry of laryngeal flame, mucoelasticity, tension, and volume of the left and right VF associated with the geriatric change [25-30]. Anterior-to-posterior longitudinal phase difference frequently seen in this subgroup might be explained by weak closing force in the anterior glottis due to the atrophic degeneration of lamina propria of the VF or laryngeal musculature [28-29]. Supraglottic hyperactivity is assumed to be the compensation for the atrophic change.

Although the characteristics of young males were akin to those of elderly males, the mechanism might be different since young males are considered to be unaffected by aging. Considering the fact that all young males in the present study were physicians, decreased mucosal wave and supraglottic hyperactivity might result from the unconscious attempt to phonate in a pressed voice to be authoritative and convincing to patients. Anterior-to-posterior opening type might be associated with a weak glottal closure resulting from vocal fatigue due to the chronic laryngeal overtone.

The high incidence of lateral phase difference, asymmetry, atrophic change, and anterior gap in elderly females might come from the abovementioned left-right structural or functional asymmetry, or degenerative atrophic change due to geriatric change [25-30]. It is counterintuitive that atrophic change was more frequent and severer in elderly females than elderly males in the present study since past studies reported the incidence of atrophic change to be 36% in elderly females and 68% in elderly males [25]. The discrepancy might come from the difference in evaluating modality: HSDI films used in the present study contained only the adducted status during phonation with black-and-white images while videostroboscopy and laryngeal fiberscopy can usually assess both abducted and adducted conditions with full-color images (e.g., bowing of the VF, the prominence of the cartilaginous portion).

Patel et al. reported that HSDI was augmentative to videostroboscopy in the assessment of moderate-to-severe dysphonia, especially in cases with jitter exceeding 0.87%, shimmer exceeding 4.4%, and signal-to-noise ratio lowering 15.4 dB [3], into which 17% of all subjects in the present study were included. Therefore, it is inferred that videostroboscopy is not sufficient in describing the VF dynamics even in normative voice. Limitations include the relatively small number of elderly subjects, the lack of middle-aged or adolescent subjects, and the lack of evaluation with self-rating scales. Although we paid good attention to the angle of the inserted endoscope during examination, parallax could be a complicating factor during examination with a rigid endoscope as Hibi et.al pointed out [31]. Still, from the best of our knowledge, the present study is the first report that referred to the age- and gender-related differences of HSDI features in normophonic subjects and it can serve as a database in the future HSDI researches.

Conclusions

We described the HSDI features of VF vibrations in vocally healthy subjects using an assessment form, and discussed age- and gender-related differences. These characteristics should be taken into account in the HSDI assessment.

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