

Vocal-fold vibration of patients with Reinke's edema observed using high-speed digital imaging



Takeshi Watanabe, Kenichi Kaneko*, Koichi Sakaguchi, Haruo Takahashi

Department of Otolaryngology—Head and Neck Surgery, Nagasaki University Graduate School of Biomedical Sciences, 1-7-1 Sakamoto, Nagasaki 852-8501, Japan

ARTICLE INFO

Article history:

Received 14 April 2015

Accepted 15 February 2016

Available online 11 March 2016

Keywords:

High-speed digital imaging

Videostroboscopy

Vocal-fold vibration

Reinke's edema

ABSTRACT

Objective: We aimed to assess the vocal-fold vibration of patients with moderate-to-severe Reinke's edema using high-speed digital imaging (HSDI) and videostroboscopy and to confirm HSDI usefulness in examining the vocal folds with Reinke's edema.

Methods: We examined the vocal folds of seven patients (six severe and one moderate; six females and one male; aged 55–74 years; mean 64.7 years) with Reinke's edema using HSDI and videostroboscopy. The following characteristics were analyzed: glottic closure, mucosal-wave propagation, left–right asymmetry, phase shift, frequency difference, periodicity, and contact of the true vocal fold with the false vocal fold.

Results: HSDI revealed complete glottic closure, anterior–posterior phase shift, and obvious contact of at least one side of the edematous true vocal fold with the ipsilateral false vocal fold in all patients. Mucosal-wave propagation increased in six patients and decreased in one. Left–right asymmetry was observed in six patients. Left–right phase shifts and left–right frequency differences were observed in four and two patients, respectively. The vibration was periodic in four patients, quasi-periodic in three, and aperiodic in none. Anterior–posterior frequency differences were not observed for any patient. The vocal-fold vibration always synchronized with strobolights in two patients, while the vibration occasionally and never synchronized in two and three patients, respectively. In one patient whose vibration occasionally synchronized, videostroboscopy could not reveal the slight left–right frequency difference of the vibration.

Conclusion: It was often difficult to observe vocal-fold vibration correctly in patients with severe Reinke's edema using videostroboscopy. However, HSDI was useful for examining these patients. Our results suggest that HSDI can be very useful for examining the vocal folds of patients with severe Reinke's edema.

© 2016 Elsevier Ireland Ltd. All rights reserved.

1. Introduction

Reinke's edema is a swelling of the vocal fold in Reinke's space that is strongly related to smoking. It is associated with a characteristic hoarse voice that is rough and of low pitch, and it may present with stridor if the edema is marked. Conservative

treatments, such as smoking cessation, voice therapy, and medication, are generally effective against mild edema; however, microphonosurgery is often necessary in severe cases.

In the vocal fold with Reinke's edema the stiffness of the vocal fold cover (epithelium and Reinke's space) is decreased, whereas the mass of the cover and depth of the vibratory edge are increased [1]. These pathological changes affect the vibratory manner of the vocal folds during phonation.

Observation of vocal-fold vibration in the patients with dysphonia is crucial for accurate diagnosis and evaluation

* Corresponding author. Tel.: +81 95 819 7349; fax: +81 95 819 7352.
E-mail address: kkaneko@nagasaki-u.ac.jp (K. Kaneko).

before and after treatment. Videostroboscopy is widely used to observe vocal-fold vibration in clinic. In particular, pre- and post-operative stroboscopic assessment of Reinke's edema is important for phonosurgery [2]. Generally, stroboscopy of the vocal folds with Reinke's edema during phonation reveals complete glottic closure with asymmetric movements of the bilateral vocal folds. Successive vibrations are often aperiodic. The amplitude of horizontal excursion is often small; however, the mucosal wave is usually marked [1,2].

However, clinical use of videostroboscopy is limited because it relies on periodic vocal-fold vibration and a stable phonation frequency to activate the strobolights; these are conditions that are not always present in disordered voices [3]. Conversely, high-speed digital imaging (HSDI) has a clear advantage over videostroboscopy because it can visualize vocal-fold vibrations irrespective of their periodicity and stability of phonation frequencies. However, little is known regarding vocal-fold vibration in patients with Reinke's edema when observed using HSDI. Thus, we assessed patients with moderate-to-severe Reinke's edema using HSDI and videostroboscopy to assess whether HSDI was useful for vocal-fold examination in such patients.

2. Materials and methods

We examined vocal-fold vibration of seven patients with moderate-to-severe Reinke's edema (six graded as type III and one as type II under Yonekawa's classification [4], six females and one male, aged 55–74 years, mean: 64.7 years) using a HSDI system and videostroboscopy. The HSDI system comprised a high-speed digital camera (EXILIM PRO EX-F1, Casio Computer Co., Ltd., Tokyo), a 70° rigid laryngeal endoscope (STF-1, Nagashima Medical Instruments Co., Ltd., Tokyo), and a xenon 300-W light source (CLV-S40Pro, Olympus Co., Tokyo) [5]. This system enabled transoral observation of each vocal-fold vibration at a rate of 1200 frames per second (fps) with a resolution of 336 × 96 pixels. Videostroboscopy was transnasally performed with a stroboscope (LS-3A, Nagashima Medical Instruments Co., Ltd., Tokyo) straight after laryngeal observation with usual continuous light source, coupled with a flexible video endoscopy system (ENF-VH and OTV-S7Pro, Olympus Co., Tokyo). LS-3A uses a sensitive contact microphone to extract a patient's fundamental phonation frequency. The patients were asked to phonate the sustained vowel /e/ at a comfortable pitch and intensity during the examination.

HSDI and videostroboscopy images were used to analyze the vocal folds by replaying them at various speeds. In addition, kymograms were constructed from HSDI results using our original software. The vocal-fold vibration was rated per subject by three laryngologists (T.W., K.K., and K.S.) according to the following parameters: glottic closure (1: complete, 2: incomplete, 3: no closure); mucosal-wave propagation (1: decreased, 2: normal, 3: increased), left–right symmetry (1: symmetric, 2: slightly asymmetric, 3: obviously asymmetric), left–right phase shift (1: absent, 2: slight, 3: obvious), anterior–posterior phase shift (1: absent, 2: slight, 3: obvious), left–right frequency difference (1: absent, 2: slight, 3:

obvious), anterior–posterior frequency difference (1: absent, 2: slight, 3: obvious), periodicity (1: periodic, 2: quasi-periodic, 3: aperiodic), contact of the true vocal fold with the false vocal fold (1: absent, 2: slight, 3: obvious) and synchronization with strobolights (1: always, 2: occasionally, 3: never). Here *quasi-periodic* in periodicity implied that even though it was not strictly periodic in time and in amplitude, it did have some periodicity in cycles. Each rater provided ratings twice, with a 1-month interval between ratings, and inter-rater, and intra-rater reliabilities were calculated using Fleiss' Kappa. A large majority of the rating by three raters were chosen as the patients' final result for each parameter.

This study was approved by the institutional review board at Nagasaki University Hospital.

3. Results

The outcomes of the vocal-fold observations are shown in Table 1. The inter-rater reliability was 0.93. The intra-rater reliabilities ranged from 0.86 to 1.00.

HSDI revealed complete glottic closure in all patients. Anterior–posterior phase shift was observed in all, obviously in four and slightly in three. Obvious contact of at least one side of the edematous true vocal fold with the ipsilateral false vocal fold was observed in all, and also with the contralateral false vocal fold in two among them. Mucosal-wave propagation increased in six patients and decreased in one. Obvious and slight left–right asymmetry was observed in five and one patients with type-III edema, respectively. Left–right phase shifts and left–right frequency differences were observed in four and two patients, respectively. The vibration was periodic in four patients, quasi-periodic in three, and aperiodic in none. Anterior–posterior frequency differences were not observed for any patient. The vocal-fold vibration always synchronized with strobolights in two patients, while the vibration occasionally and never synchronized in two and three patients, respectively, even after any number of trials. In two patients whose vibration always synchronized and in one whose vibration occasionally synchronized, videostroboscopy produced similar findings as were observed for HSDI. However, in another patient whose vibration occasionally synchronized, videostroboscopy could not reveal the slight left–right frequency difference of the vibration.

Fig. 1 shows representative HSDI images of the vocal-fold vibration for Patient 1 with increased mucosal-wave propagation, obvious left–right asymmetry, obvious anterior–posterior phase shift, and contact of the true vocal fold with the ipsilateral false vocal fold.

4. Discussion

In the present study, HSDI revealed complete glottic closure, increased mucosal-wave propagation, left–right asymmetry, anterior–posterior phase shift, and contact of at least one side of the true vocal fold with the ipsilateral false vocal fold in most patients. Among these findings, anterior–posterior phase shift and contact between the true and false vocal fold have not been presented in the past studies. In general, irregular vibration of

Table 1

Outcome of observation of vocal fold vibration.

Patient	Age	Sex	Grade (Yonekawa's classification)	HSDI								Synchronization with strobolights	
				Glottic closure	Mucosal-wave propagation	Left–right symmetry	Phase shift		Frequency difference		Periodicity		Contact with false vocal fold
							Left– right	Anterior– posterior	Left– right	Anterior– posterior			
1	55	M	III	Complete	Increased	Obviously asymmetric	Absent	Obvious	Absent	Absent	Periodic	Obvious	Never
2	61	F	III	Complete	Increased	Slightly asymmetric	Slight	Slight	Absent	Absent	Periodic	Obvious	Occasionally
3	63	F	II	Complete	Increased	Symmetric	Absent	Slight	Absent	Absent	Periodic	Obvious	Always
4	64	F	III	Complete	Increased	Obviously asymmetric	Obvious	Obvious	Absent	Absent	Quasi-periodic	Obvious	Always
5	65	F	III	Complete	Increased	Obviously asymmetric	Obvious	Obvious	Slight	Absent	Quasi-periodic	Obvious	Occasionally
6	71	F	III	Complete	Decreased	Obviously asymmetric	Absent	Slight	Absent	Absent	Periodic	Obvious	Never
7	74	F	III	Complete	Increased	Obviously asymmetric	Obvious	Obvious	Obvious	Absent	Quasi-periodic	Obvious	Never

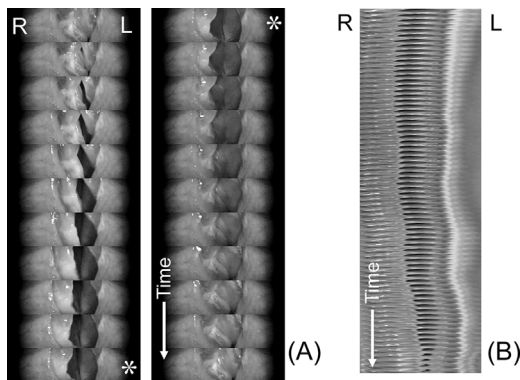


Fig. 1. Vocal-fold vibration obtained through HSDI for Patient 1. (A) Image sequence in one cycle showing complete glottic closure, increased mucosal-wave propagation, obvious left–right asymmetry, obvious anterior–posterior phase shift, and contact of the true vocal fold with the ipsilateral false vocal fold. (B) A kymograph showing periodic vocal-fold vibration.

the vocal folds can produce a rough voice. Verdonck-de Leeuw et al. reported that the presence of mucus, left–right phase shift, and short-term frequency and amplitude modulation caused voice roughness [6]; however, these were not always observed in our study. Krival et al. reported that those who used supraglottic phonation had significantly rougher voice than those who used glottic phonation in patients after pediatric laryngotracheal reconstruction [7]. We hypothesize that anterior–posterior phase shift and contact between the true and false vocal fold will also lead to roughness and are, therefore, important findings in patients with moderate-to-severe Reinke's edema.

Videostroboscopy shows only illusory slow motion images of the vibrating vocal folds, while HSDI can show real vocal-fold vibration. In our study, the findings of the vocal-fold vibration assessed with videostroboscopy were the same as

assessed with HSDI in three patients. On the contrary, videostroboscopy could not correctly reveal the vocal-fold vibration in other four patients with type-III edema; in one patient videostroboscopy could not reveal the left–right frequency difference, even when vibration could occasionally synchronize with strobolights. In three patients, because the vocal-fold vibration could never synchronize with strobolights, it was impossible to observe the vocal-fold vibration in detail and the vibration was assessed as aperiodic. In contrast, HSDI was not only able to visualize each vibration cycle but also revealed that the vibration was periodic or quasi-periodic in all patients and not aperiodic in three as assessed with videostroboscopy. Furthermore, left–right frequency differences were observed in two patients in whom videostroboscopy could not reveal it.

We consider that the failure in vibration and strobe synchronization in three patients occurred because the hoarse voice in these patients made it impossible to extract a single stable phonation frequency to activate the strobolights. Aperiodic vibrations are thought to be easier to identify on videostroboscopy than HSDI [3], because videostroboscopy cannot produce smooth-vibration images during aperiodic vibrations; however, this was not true in our study. Even if the vibration could not synchronize with strobolights, it did not always mean that the vibration was aperiodic. From the point of view of assessing periodicity correctly, we consider HSDI is superior to videostroboscopy. When assessing periodicity by HSDI, however, it may be time-consuming to check many images of cycles; moreover, the results may be unreliable. We consider that kymography constructed from HSDI is helpful for assessing periodicity easily and precisely without laborious analysis of images.

Recent clinical reports have demonstrated the observation of vocal-fold vibration by HSDI at a rate of 1200–4000 fps [3,5,8,9]. The frame rate of 1200 fps in our study may seem

low when compared with other reports; however, we consider it was adequate for vocal-fold observation in Reinke's edema because the fundamental frequencies were approximately 100 Hz.

Finally, precancerous or cancerous lesions or scars from previous surgery can coexist with Reinke's edema. We consider that it is important to observe vocal-fold vibration in patients with severe Reinke's edema using HSDI to ensure that we detect these before surgery.

5. Conclusion

HSDI revealed complete glottic closure, increased mucosal-wave propagation, left–right asymmetry, anterior–posterior phase shift, and contact of at least one side of the true vocal fold with the ipsilateral false vocal fold in most patients with moderate-to-severe Reinke's edema. It was often difficult to observe vocal-fold vibration in patients with severe Reinke's edema using videostroboscopy. However, HSDI was useful for examining these patients.

Conflict of interest

We declare that we have no conflicts of interest to disclose.

References

- [1] Hirano M, Bless DM. Typical vibratory patterns in vocal pathologies and their clinical implications. In: *Videostroboscopic examination of the larynx*. San Diego: Singular Publishing Group; 1993. p. 119–89.
- [2] Boehme G, Gross M. Stroboscopy. In: *Stroboscopy*. London: Whurr Publishers; 2005. p. 18–106.
- [3] Kendall KA. High-speed laryngeal imaging compared with videostroboscopy in healthy subjects. *Arch Otolaryngol Head Neck Surg* 2009;135:274–81.
- [4] Yonekawa H. A clinical study of Reinke's edema. *Auris Nasus Larynx* 1988;15:57–78.
- [5] Kaneko K, Sakaguchi K, Inoue M, Takahashi H. Low-cost high-speed imaging system for observing vocal fold vibration in voice disorders. *ORL J Otorhinolaryngol Relat Spec* 2012;74:208–10.
- [6] Verdonck-de Leeuw IM, Festen JM, Mahieu HF. Deviant vocal fold vibration as observed during videokymography: the effect on voice quality. *J Voice* 2001;15:313–22.
- [7] Krival K, Kelchner LN, Weinrich B, Baker SE, Lee L, Middendorf JH, et al. Vibratory source, vocal quality and fundamental frequency following pediatric laryngotracheal reconstruction. *Int J Pediatr Otorhinolaryngol* 2007;71:1261–9.
- [8] Sekimoto S, Tsunoda K, Kaga K, Makiyama K, Tsunoda A, Kondo K, et al. Commercially available high-speed system for recording and monitoring vocal fold vibrations. *Acta Otolaryngol* 2009;129:1524–6.
- [9] Kaneko K, Watanabe T, Inoue M, Takahashi H. A novel high-speed digital imaging system for assessing vocal fold vibration. *Acta Medica Nagasakiensia* 2014;59:37–40.