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Videostrobokymography: A New Method for the Quantitative Analysis of Vocal Fold Vibration

Myung-Whun Sung, MD, PhD; Kwang Hyun Kim, MD, PhD; Tae-Yong Koh, MD; Tae-Young Kwon, MD; Ji-Hun Mo, MD; Seung-Ho Choi, MD; Jae Sung Lee, MS; Kwang Seok Park, PhD; Eom Joon Kim, MS; Mee Young Sung, PhD

Objectives: **To develop a new analysis method for the quantitative assessment of vibration of the vocal folds, using conventional videostroboscopic image data.** ***Methods:*** **We used prerecorded videostroboscopic images to evaluate quantitatively the vibration of the vocal folds. Successive images were converted as digital images by means of an image-grabbing board, processed for analysis, and reconstructed as kymograms by rearranging the same lines of all processed images along the time axis.** ***Results:*** **We developed a new technique for evaluating the vibration of the vocal folds. The vibrations of multiple vocal fold regions were easily and objectively evaluated by this technique. The objective parameters, such as open quotient and asymmetry index, could be obtained easily using this technique.** ***Conclusions:*** **Videostrobokymography demonstrated objectively the vibrations of several vocal fold regions at the same time. This technique has the potential to be a new tool to analyze and monitor the pathological changes and treatment results of vocal fold movement in a more refined quantitative fashion, using videostroboscopic images.** ***Key Words:*** **Videostrobokymography, stroboscopy, vocal fold mucosa.**

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From the Departments of Otorhinolaryngology (M.-W. S., K.H.K., T.-Y. K., J.-H.M., S.-H.C.) and Biomedical Engineering (J.S.L., K.S.P.), Seoul National University College of Medicine, Seoul, Korea; and the Department of Computer Science (E.J.K., M.Y.S.), Inchon University, Inchon, Korea.

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Send Reprint Requests to Myung-Whun Sung, MD, PhD, Department of Otorhinolaryngology, Seoul National University College of Medicine, 28 Yongon-dong, Chongno-gu, Seoul, Korea 110–744.

INTRODUCTION

The vocal folds play a major role in phonation, generating a pressure in the subglottis with the expired air from the lung. When the pressure exceeds the resistance of the vocal folds, mucosal waves propagate from the anterior to posterior, as well as inferior to superior, margins of the vocal folds. Because the mucosal vibration is the final determinant of the quality of voice, various tools have been developed to evaluate the vibratory movement of the vocal folds.[1–3]

Among the various tools, stroboscopy is the most widely used modality to examine the vocal fold vibration during phonation. Stroboscopy makes it possible to observe the movement of the vocal folds in slow motion using flickering light synchronized to the mucosal vibration of the vocal folds. The interpretation of stroboscopic images, however, mainly depends on the subjective judgment of the examiner.[2,4] For the objective evaluation of stroboscopic images, Woo[5] suggested some quantitative parameters extracted from stroboscopic images recorded in videotapes, using computer-integrated stroboscopic systems. Recently, Svec and Schutte[6] and Schutte et al. [7] introduced videokymography, a digital technique for high-speed visualization of vibration. Using this technique, an objective observation of the vibratory patterns of the vocal folds could be possible. This system, however, requires a special charge-coupled device camera for high-speed line scanning, and a vibratory pattern of only a single horizontal line of the glottal image can be obtained at a time.

In this study we developed a new technique, videostrobokymography), in which we could use previously recorded images of conventional videostroboscopy. Successive frames of video images obtained from videostroboscopy were transferred to the computer, and kymograms of multiple selected portions of the vocal folds in the same period could be simultaneously displayed.

MATERIALS AND METHODS

The hardware of videostrobokymography consists of a video recorder and a personal computer with an image-grabbing board

(Raptor-PCI, Bitflow Inc., Woburn, MA) that transfers the image signal from the videotape to computer memory. We also developed a software operating in Windows 95 (Microsoft Co., Redmond, WA) for image-grabbing, processing, and analysis.

Laryngeal stroboscopic images, when patients phonated constant vowel /*i*/, were recorded, using a conventional videostroboscopy system (Kay Elemetrics, Lincoln Park, NJ) with a 70° telescope on fast mode. In the software, we can browse the stroboscopic images of the videotape. The most stable image segment with sufficient duration was chosen to be analyzed. It required so much time and computer memory space to analyze the whole image data that the software was designed to freely select a small rectangular region of interest to save time and memory space. From the stroboscopic images, successive images of the selected rectangular region were transferred to the memory of the computer and could be displayed on the monitor sequentially. Using a mouse, the user again chose a line of interest where he or she wanted to analyze the pattern of mucosal vibration. The same lines of consecutive images were rearranged in a new window from top to bottom along a vertical time axis, constructing a kymogram. This kymogram depicted the vibratory pattern of the mucosal edges of the vocal folds at the selected line.

When multiple lines of interest were selected, corresponding kymograms could be displayed on the monitor. Before constructing a kymogram, the longitudinal axis of glottal area was aligned with the Y-axis of the window to compensate for obliqueness of the glottal areas. Quantitative parameters such as open quotient (OQ) and the asymmetry index (AI) could be calculated from the constructed kymogram programmatically.

Normal subjects and some pathological cases were investigated to evaluate the clinical applicability of this system.

RESULTS

With videostroboscopy, we could obtain stroboscopic images at a rate of 30 frames per second (for the National Television Standards Committee system). Because the glottal area is concerned, a rectangular area of glottis is selected and transferred to computer memory (usually 70–100 frames). Because it was not always easy to make a good vertical alignment of the glottis during videostroboscopic examinations, a correction of the longitudinal glottal axis was necessary in many cases for better analysis. Figure 1 shows the realignment of the glottal axis. A imaginary line connecting the anterior and posterior glottic ends at the maximally opened glottis was drawn, and the whole image was rotated to make this line vertical for all frames. By correcting the glottal axis, the asymmetrical motion of the vocal fold mucosa was better visualized. After image correction, kymograms were constructed by selecting multiple lines on the image, and we could analyze the vocal folds movement and calculate quantitative parameters.

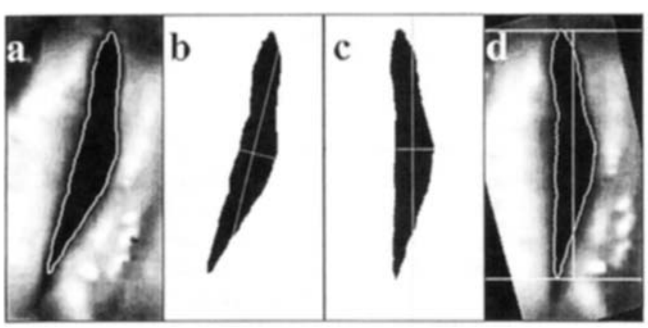

Fig. 1. Rotation of the glottal axis to compensate the obliqueness from the relative orientation of patient's larynx and the endoscope. **A.** Glottal image before correction; the edges of the vocal folds were marked with a white line at the maximal opening. **B.** A longitudinal line drawn on the extracted image of the glottal area was used as a reference line to rotate the image. **C.** Extracted glottal area after rotation. **D.** Real glottal image after rotation.

The OQ, which is the ratio of the open and total phases, could be easily obtained from each selected area of the glottis (Fig. 2). The open phase, which corresponds to the dark rhomboid area of the videostrobokymograms (VSKs), was extracted, and the OQ was easily calculated.

The asymmetrical movement of the vocal folds was quantified by measuring the size of each triangular area on both sides of Figure 2. Because the position of the glottis in the recorded images may not be stable, because of the inevitable shaking of the stroboscope and/or the patient, the asymmetrical movement could not be accurately assessed without correction in most cases. Thus the dark rhomboid area of the VSK, which stands for the open phase, was realigned so that a line connecting the upper and lower angular points of the rhomboid area would be parallel to the vertical line of the image (Fig. 3). After correction of the motion artifact, AI could be calculated as follows:

AI = (left glottal area − right glottal area) / (left glottal area + right glottal area) × 200 (%).

Figure 4 shows VSKs from a normal person. The numbers indicate the positions of the lines used for the reconstruction of the corresponding kymograms. The examiner could choose as many lines of interest on the glottis as he or she wanted to analyze, just by clicking a

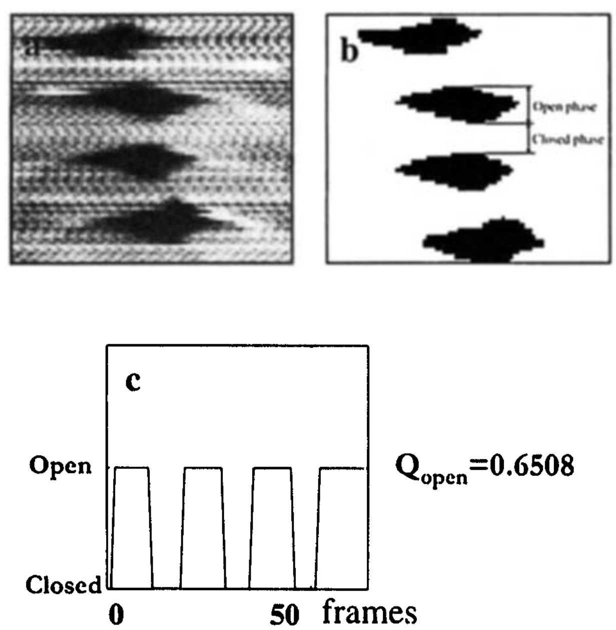

Fig. 2. The open quotient at different parts of the vocal folds can be easily calculated by simply measuring the dark and bright areas on each corresponding kymogram. **A.** Initial kymogram. **B.** Extraction of open (black area) and total phases. **C.** A diagram showing the open phase and the closed phase. Q_{open} = open quotient.

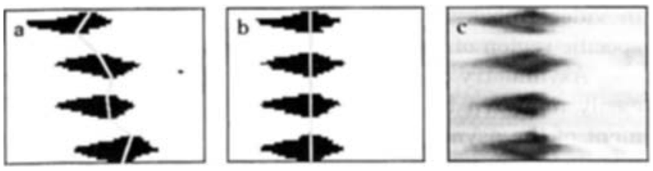

Fig. 3. Correction of the shaking motion artifacts. **A.** Lines connecting the upper and lower angular points of each open area were drawn. **B.** These lines were connected and corrected to be parallel to the vertical axis of the image. **C.** Correction on a real kymogram.

mouse. The open and closed phases and symmetrical vibratory movement over multiple cycles of mucosal waves were well displayed.

Figure 5 shows VSKs of a patient with unilateral vocal fold palsy. Irregular vibratory movements and incomplete closure over the entire length of the vocal folds were well documented using this technique. Videostrobokymography provided a good documentation of a marked deviation of the right mucosal edge toward the left, which might not be well ascertained in a merely visual observation of the videostroboscopic images

Figure 6 shows VSKs from a patient with a vocal polyp. In VSKs taken at different parts of the glottis, the absence or reduction of the open phase at the site of polyp and at the anterior part of the glottis was observed, while increased open phases at the other parts were visualized.

Figure 7 shows VSKs of a patient with sulcus vocalis on his left vocal fold. Open phases were increased at the middle and posterior part of the glottis with minimal touching of both mucosal edges. The VSK from line 2 showed that both mucosal edges did not contact, even though the edge of the right vocal fold moved to the left over the midline.

DISCUSSION

Many techniques have been developed to study the vibration of the vocal folds, such as stroboscopy, high-speed photography, electroglottography, photoglottography, and videokymography.[1–3,6,8]

Development of high-speed photography made modern research on the movement of the vocal folds possible.

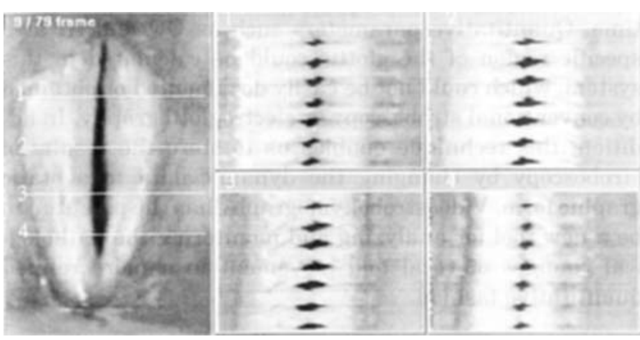

Fig. 4. Videostrobokymograms (VSKs) from a normal person. The numbers indicate the positions of lines of interest used for the reconstruction of the corresponding kymograms on the right side of the figure. A periodic, symmetrical vibratory movement of the vocal fold is clearly observed (the vertical axis is a time axis in the kymogram).

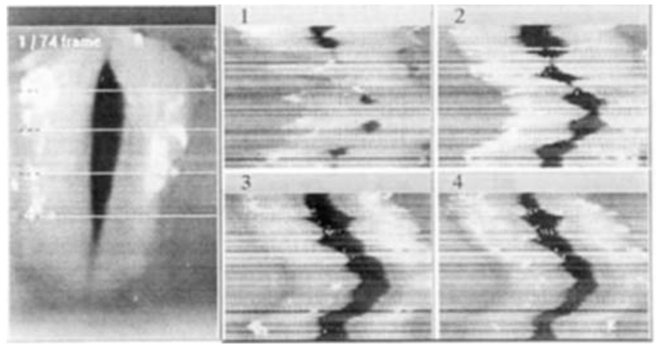

Fig. 5. Videostrobokymograms in a patient with unilateral vocal fold palsy. 1, 2, 3, and 4: VSKs of selected lines on the left glottal image. Irregular vibratory movements over the entire length of the vocal fold and incomplete closure of the vocal fold were well visualized. A marked deviation of the mucosal edges of the right vocal fold toward the left vocal fold was clearly seen.

High-speed photography could register several thousands frames of images per second.[8] It was very expensive, however, and the machine was difficult to handle and too noisy for both the image and the sound to be recorded simultaneously.

Modern videostroboscopy overcame such limitations. Videostroboscopy today is one of the standard methods used to examine vocal fold movement.[2,4] The stroboscope produces flashes of light intermittently at a frequency slightly lower than that of the vocal fold vibration. A phase delay of consecutive light flashes makes it possible to observe an averaged vibratory movement of the vocal folds in an illusory slow motion and allows assessment of the change in the vocal fold mucosal movements over time. Its interpretation is mainly based on subjective assessment and requires well-trained eyes. In addition, the results should be stored on videotapes, which are difficult to store, and it is difficult to retrieve the information in office practice.

Hirose et al.[9,10] developed a high-speed digital imaging method using a solid-state image sensor attached to a conventional camera system. It could obtain almost 4,000 frames of an image per second. Svec and Schutte[6] and

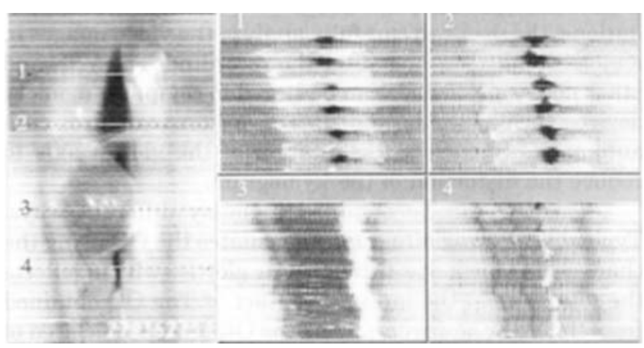

Fig. 6. Videostrobokymograms in a patient with vocal polyp. *1*, *2*, *3*, and 4: VSKs of selected lines on the left glottal image. An absence and decrease of the open phase at the site of the polyp and the anterior part of the glottis, respectively, were clearly documented. Other parts of the glottis showed a rather increased open phase.

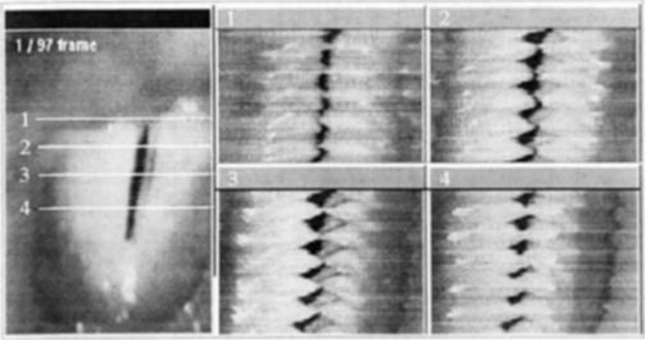

Fig. 7. Videostrobokymograms in a patient with sulcus vocalis. Open phases were increased, especially at the middle and posterior part of the glottis. The videokymogram from the line 2 showed that there was no actual mucosal contact, despite the mucosal movement over the midline.

Schutte et al.[7] modified a preexisting CCD camera to get line images of the glottis at a rate of about 8,000 images per second. These high-speed photographic methods may be substitutes for stroboscopy if they become less time-consuming and less expensive.[9,11] On the other hand, Woo[5] quantitatively analyzed the glottal area waveform obtained from previously recorded stroboscopic images. This approach required little or no additional equipment.

In this study, we developed a new analysis system, videostrobokymography, in which we hybridized the idea of videokymography to videostroboscopy. Videokymography as developed by Svec and Schutte[6] and Schutte et al.[7] is basically a line-scanning system. During a laryngeal examination, a CCD camera selects one horizontal line and gets line images at the speed of about 8,000 images per second. These successive line images are displayed on the monitor in real time. The main disadvantage of the system is that only a single kymogram of the scanned line can be obtained by one examination; other areas of the vocal folds cannot be observed at the same time. For the evaluation of other horizontal lines, additional laryngeal examinations are needed.[6,7]

Videostrobokymography as introduced in this study enables us to make multiple kymograms from multiple lines of interest using prerecorded video images. Because videostrobokymography does not require repeated examinations, the user can carefully analyze the video images in a more detailed fashion after the recording. The VSK and other necessary images can be stored in computer memory devices such as the hard disk. This system can also semi-automatically correct the rotation of the glottal axis to reduce the distortion of the kymogram.

The OQ can be obtained in many different ways. Typically, electroglottography calculates the OQ using the change of impedance through the glottis, which reflects the total sum of the mucosal contact.[4,8] The OQ obtained from the VSK, however, means the OQ of a specific area of the vocal fold. By selecting multiple lines of interest, we can get much more detailed information on the motions of different parts of the vocal fold. Therefore it is impossible to directly compare the OQ with that from other methods such as electroglottography or photoglottography. The OQ in videostrobokymography is a figure obtained from a specific region of the glottis, not from the whole glottis.

Asymmetry index is a new parameter that can be easily analyzed by videostrobokymography. The assessment of the asymmetrical vocal fold movement has been mainly based on subjective visual analysis. Quantification of the asymmetrical movement of the vocal fold mucosa may provide important information in assessing the vibration of pathological vocal folds. The AI proposed in this study has a range of 0% to 200%. If the vibration of both vocal folds is perfectly symmetrical, it will be 0%, and if one vocal fold is fixed in the median position without any mucosal vibration, it will reach up to 200%. The clinical significance of AI should be further evaluated in various pathological conditions.

The image of stroboscopy is not a true image but an optical illusion of the vocal fold vibration that is based on the assumption that the vibration is stable and regular. When the voice is so noisy and aperiodic that the extraction of the fundamental frequency is practically impossible, it is difficult or impossible to see the vibratory movement of the vocal fold by videostroboscopy. Because videostrobokymography analyzes the recorded images from stroboscopy, VSKs are not the trace of real mucosal edges, but consecutive pictures in an illusory slow motion. In terms of direct viewing of the vocal fold mucosa, videokymography developed by the authors cited earlier has a strong point, in that the system does not depend on the periodicity of the vibration. However, despite an inherent limitation of stroboscopy, videostrobokymography provided many quantitative parameters and enabled us to objectively measure and evaluate the motion of the vocal fold mucosa at multiple selected regions of the glottis. In addition, as seen in Figure 7, videostrobokymography could demonstrate a new finding, which could not have been easily realized before.

CONCLUSION

We developed a new analysis method of the vibration of the vocal folds, videostrobokymography. Rearrangement of one active horizontal line from successive frames of prerecorded stroboscopic images, which were displayed from top to bottom along the time axis, provided a static image of vibration at a specific part of the vocal folds over time. Quantitative parameters such as OQ and AI at a specific region of the glottis could be calculated in this system, which could not be easily documented or obtained by conventional stroboscopy or electroglottography. In addition, this technique enables us to store the results of stroboscopy by changing the dynamic data to a static graphic form. Videostrobokymography has the potential to be a new tool for analyzing and monitoring the pathological changes of vocal fold movement in a more refined quantitative fashion.

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