Imaging and Analysis of Human Vocal Fold Vibration Using Two-Dimensional (2D) Scanning Videokymography

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Summary: Objective. Laryngeal videokymography and high-speed digital kymography are the currently available techniques for studying aperiodic vibration of the vocal folds. However, videokymography has a fundamental limitation that only linear portions of the vocal fold mucosa can be visualized, whereas high-speed digital kymography has the disadvantages of lack of immediate feedback during examination and considerable waiting time before kymographic visualization. We developed a new system, two-dimensional (2D) scanning videokymography, that provides a possible alternative for evaluation of the vibratory pattern of the vocal folds. Herein, we report the application of 2D scanning videokymography for visualization of vocal fold vibration in humans and an analysis of its parameters.

Materials and Methods. Two young healthy volunteers (one man and one woman) took part in this study. The vibratory patterns of their vocal folds were evaluated using 2D scanning videokymography and laryngeal stroboscopy.

Results. Two-dimensional scanning videokymography provided a high-definition image of the vibratory movements of the vocal folds. In analysis of the images acquired by the device, various parameters including fundamental frequency; ratio of the vibratory phases; phase, amplitude, and glottal area symmetry; and cycle-to-cycle variability were extracted.

Conclusions. Our results indicate that 2D scanning videokymography is a useful and promising tool for visualization of the vibratory movement of the vocal folds. This new technique might improve our understanding of the mechanism of vocal fold vibration and contribute to voice research as well as clinical practice.

Key Words: Videokymography–Vocal folds–Vibration–Two-Dimensional–Human.

INTRODUCTION

Vibration of the vocal folds is integral to the physiology of voice production and the pathophysiology of vocal fold disorders; therefore, direct visual inspection of the vocal folds is essential for objective evaluation. In 1971, Gall et al[1] used a single-lens reflex camera and an indirect laryngoscopic mirror to capture vocal fold movements for the first time. The technique, laryngeal photokymography, allowed visualization of the entire area of the vocal fold by a camera with a slit shutter that moved from inferior to superior or superior to inferior in front of a fixed film, but the system was never realized in a commercially available form.[2,3]

Currently, laryngeal stroboscopy is widely used to study the vibration of the vocal folds in clinical practice. However, this technique usually shows somewhat illusory slow-motion images of the vibrating vocal folds and provides a clear image only when vocal fold vibrations are periodic with stable phonation frequency.[4] Videokymography was developed to overcome the inherent limitation of stroboscopy in visualizing aperiodic vibrations.[5] The three kymographic techniques that are in use currently for the visualization of vocal fold vibration are videokymography,[5] high-speed digital kymography,[6,7] and strobovideokymography.[8,9] The videokymographic system delivers kymographic images directly in real time on a video screen, whereas the latter two methods provide software-based reconstruction of kymographic images extracted from high-speed laryngoscopy and laryngeal stroboscopy, respectively. Among the three techniques, only videokymography and high-speed digital kymography are useful for visualizing aperiodic vibrations of the vocal folds.[10]

Videokymography was developed to provide kymographic imaging encoded as a standard video signal[5] and can project the kymographic images of vocal fold vibrations directly on a standard video monitor.[11] However, videokymography has the fundamental limitation that only linear portions of vocal fold mucosa can be visualized. High-speed digital kymography uses images acquired by high-speed laryngoscopy and shows the actual vibratory image of the vocal fold mucosa.[6,7] However, it has some limitations: no immediate feedback is available during examination, there is a considerable waiting time before the images are developed, recording times are short (limited to several seconds), and there are extreme demands on data storage.[2]

Our senior author, Prof. S.G.W., has developed a two-dimensional (2D) scanning videokymography system on the basis of the principle of pioneering photokymography technique

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by Gall, which might provide a possible alternative to the currently available methods.[12] We have previously reported the application of 2D scanning videokymography in the excised canine larynx model.[13] Herein, we report the application of 2D scanning videokymography in the visualization of vocal fold vibrations in healthy adult humans along with an analysis of its parameters.

MATERIALS AND METHODS

Laryngeal stroboscopic system and the two-dimensional scanning videokymography system

A laryngeal stroboscopic system (ULS-515, U-medical, Korea) was used to view the vocal fold mucosa of the subjects. The videostroboscopic examination was performed in synchronization with vibration pickup.

The 2D scanning videokymography technique was thoroughly described in our previous article.[12,13] A full-HD complementary metal oxide semiconductor (CMOS) image sensor (1920 × 1080 pixels) and rolling shutter camera (Insight-mini, HEEAN, Korea) were used in the device. A rigid endoscope (5.8 mm, 70°, 8700CKA, Storz, Germany) and a 300-W xenon light source (NOVA 300, Storz, Germany) were assembled with the device, and the system was used to visualize the vocal folds in their entirety. The video was recorded at 30 frames/s. The resolution of the final images of the 2D scanning videokymography was full HD (1920 × 1080 pixels), and because the scanning time for one frame with the rolling shutter camera was 1/30 second, the exposition time of a single line displayed in the image was 1/32 400 second.

Participants

Two healthy participants, a 33-year-old man and a 24-year-old woman, participated in this study. Neither had any history of laryngeal disorder or operation. The man was employed as a speech-language pathologist and the woman was a college student with a major in language science. Both participants were able to produce various registers. They each phonated sustained /i/ vowels in modal voice and falsetto voice, which were recorded using the laryngeal stroboscopic system and the 2D scanning videokymographic system.

Analysis of the images recorded using the two-dimensional scanning videokymography

The images recorded using 2D scanning videokymography were analyzed for various qualitative and quantitative

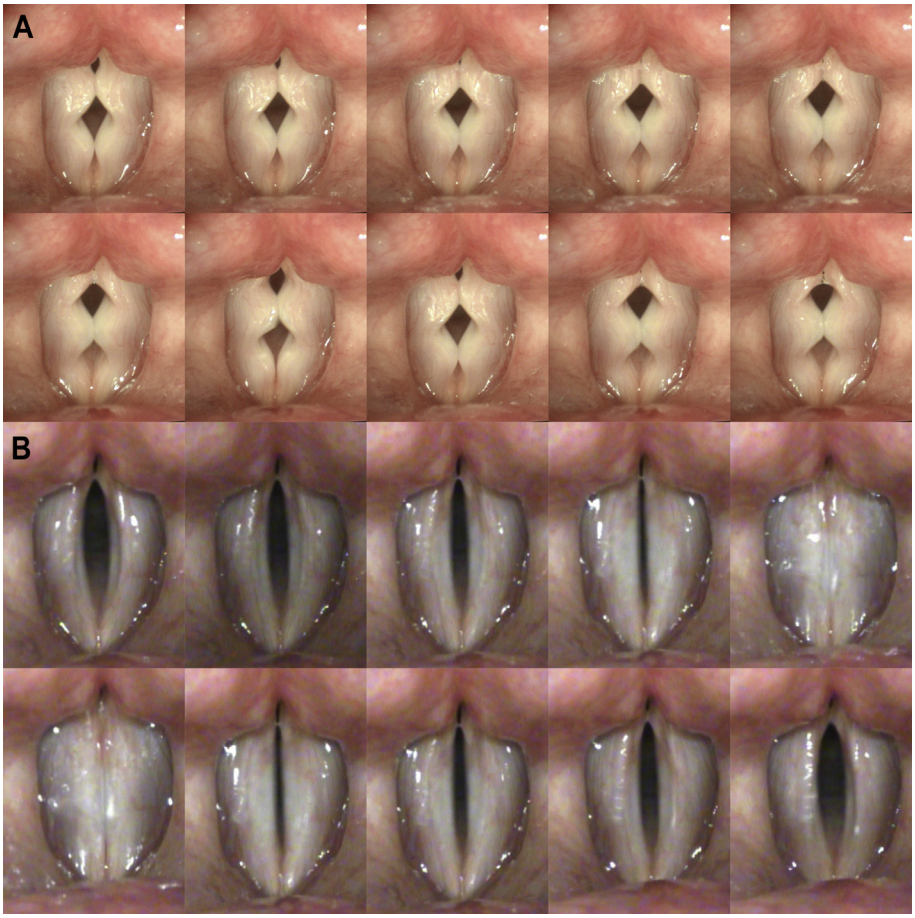

FIGURE 1. Visualization of vibratory patterns of the human male vocal folds during modal phonation using two-dimensional (2D) scanning videokymography (**A**) and laryngeal stroboscopy (**B**). The anterior part of the larynx is on the bottom. A series of still images from the 2D scanning videokymography show that the diamond-shaped glottal openings moved slowly from anterior to posterior. The images of each glottal opening reveal the vibratory movements and show both the upper and lower lips of the vocal folds. Notice that well-defined open and closed phases are seen in modal voice.

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