Clinical Practicability of a Newly Developed Real-time Digital Kymographic System

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Summary: Background. A digital kymogram shows real images of vocal fold vibration. However, DKG is difficult to use in clinical practice because the recorded image cannot be seen instantaneously after examination, as considerable encoding time is required to visualize a digital kymogram. In addition, frame-by frame analysis should be implemented to evaluate high-speed videoendoscopy data, but is time- and labor-intensive.

Purpose. The purpose of the study was to validate the clinical practicability of a real-time multislice digital kymographic system developed by the authors. We analyzed the promptness and accuracy of the examination before and after intracordal injections in patients with unilateral vocal fold paralysis.

Methods. To assess the clinical applicability of this system, six patients with unilateral vocal fold paralysis were selected. Real-time DKG was performed before and immediately after intracordal injection. We observed changes in the digital kymogram after the intracordal injection.

Results. Using this system, 10 scanning lines and up to five vertical pixel row could be obtained in real time, and the maximum acquisition time for the DKG image was 10 seconds. A digital kymogram of the patients could be instantaneously acquired, and whether the intracordal injection was appropriate or not.

Conclusion. This article is the first validation study after the development of the real-time multislice digital kymographic system. Our system may be a promising tool in clinical practice for immediate assessment of the vibratory patterns of the vocal cords. More research is necessary for further clinical validation.

Key Words: Real-time–Digital kymography–Intracordal injection–Vocal cord–Paralysis.

INTRODUCTION

Observation of vocal fold vibration in patients with dysphonia is essential for accurate diagnosis and evaluation before and after treatment. Laryngeal videostroboscopy has been used primarily in clinical practice. However, the images from videostroboscopy are illusory, as they are collected from different cycles. In addition, it is impossible to examine vocal cord vibration in cases of very irregular vocal fold vibration or short sustained vowel phonation. Videokymography[1] addresses some of the main shortcomings of videostroboscopy, and is displayed in real time, but an important limitation remains that only a single line of the laryngeal image is scanned and displayed.

Laryngeal high-speed videoendoscopy (HSV)[2] can be supplanted to solve the limitations of videostroboscopy. HSV provides more accurate information on vocal fold vibration. However, HSV has not been widely used in clinical practice because of practical limitations, such as the considerable time necessary for encoding and recording, the extremely large storage necessary for archiving, and the intense concentration required to analyze HSV images.

Recently, many researchers introduced postprocessing analytic methods from HSV data such as digital kymography (DKG),[3] glottal area waveform,[4] glottal width waveform,[5] and kymographic edge detection.[6] These methods could provide information on the characteristics of vocal fold vibrations. However, these methods, with the exception of digital kymography, might need complicated software applications, and the results are sometimes difficult to interpret. The DKG images are extracted from the HSV images and show the real vibratory image of the vocal folds. However, there are some disadvantages, such as a considerable waiting time before kymographic visualization and a recording duration limited to a few seconds.

With advanced computer performance and software technology, we developed a real-time multislice DKG system to overcome the limitations of the conventional DKG system. The purpose of this study was to demonstrate the feasibility of the real-time, multislice DKG system in clinical practice. We determined the promptness and accuracy of the analysis of unilateral vocal fold paralysis before and after intracordal injection.

MATERIALS AND METHODS

Subjects

One normophonic male (36 years old) participated in this study for the verification of the capacity of our system. Six patients with unilateral vocal fold paralysis (mean age, 57.83 years; range, 43~76 years; female:male = 1:1) were selected.

Instruments

To assess the vibratory pattern of the vocal cords, we used a black and white complementary metal-oxide-semiconductor camera with a global shutter (USC-700MF, U-medical, Busan,

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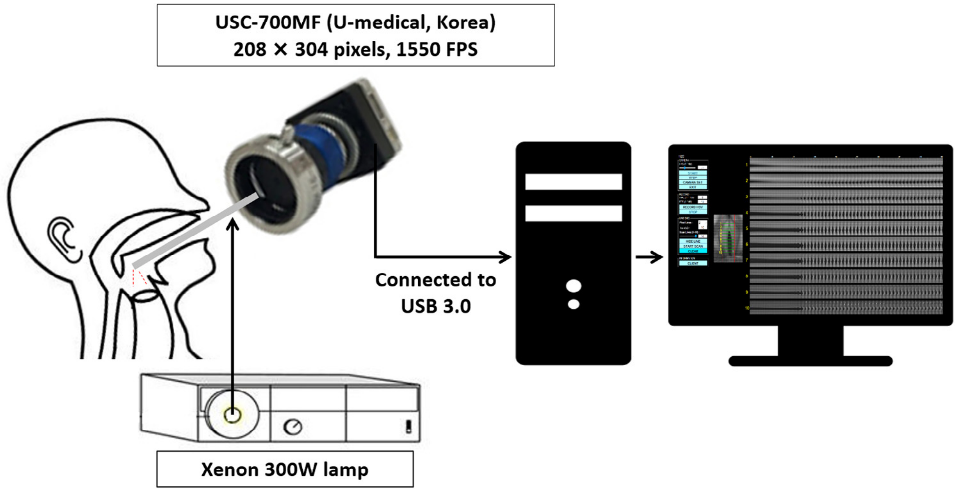

FIGURE 1. Schematic illustration of a real-time multislice DKG system.

Korea). The spatial resolution was 208 × 304 pixels and the frame rate per second was about 1500. However, the frame varies in real-time measurement depending on the computer performance. We used a 4-mm diameter, 70-degree, rigid laryngoscope (8700 CKA, Storz, Tuttlingen, Germany) connected to a zoom coupler (f = 16–34 mm, MGB, Eschbach, Germany). A 300-W xenon light source (NOVA 300, Storz, Tuttlingen, Germany) was used (Figure 1).

To create the DKG images, we developed a software program using Visual Studio Integrated Development Environment. We used an algorithm that concatenated a single vertical pixel row from each frame of the high-speed images to generate a digital kymogram the same as Tigges et al.[3] The scanning line means the perpendicular line to glottal axis. Our newly developed multiline, real-time digital kymography can be selected up to 10 scanning lines. Vertical pixel row means the minimum unit of monitor's height, and we controlled arbitrarily from one to five pixel rows.

The minimum requirements for the computer system are window 10 (64-bit), Intel Core i7, Ram 8 gigabyte, Full-HD (1920 × 1080) resolution, and USB 3.0 port. The image information of the camera is transferred to the program through USB 3.0. The camera used in this study acquires an image of about 1500 frames/s at a resolution of 208 × 304. Because the video data of about 90.45 megabytes/s (208 × 304 × 1500 × 8 bit = 758,784,000 bit/s) are transferred from the camera to the computer program, for this purpose, USB 3.0 which can transmit up to 5 gigabytes/s (625 megabytes/s) should be used.

The configuration of the user interface is shown in Figure 2 (see video clip 1). The function of the multislice DKG system could be controlled by the buttons displayed in Figure 2A. Laryngeal images for navigation are displayed in Figure 2B. The multislice DKG image is shown in Figure 2C. DKG imaging was achieved as still image files (JPEG format), and time information of each frame is saved separately as text file (txt format).

Procedures

The HSV camera connected with a laryngoscope is inserted through the oral cavity to examine the vocal cords. Ten scanning lines, a recording time of 10 seconds, and two vertical pixel rows were set, and the examination was performed after the scanning line position was adjusted in the navigation laryngeal image.

All participants were instructed to phonate a sustained vowel /e/ or /i/ with comfortable pitch and intensity during DKG examination. When recording starts using the foot switch or start button, digital kymogram images can be obtained in quasi-real time (see video clip 2). The navigation laryngoscope video image continues to be displayed after 10 seconds.

All patients with vocal cord paralysis were checked by real-time DKG before and immediately after intracordal injection. To evaluate whether the amount and site of the injection were appropriate, we classified the state of the intracordal injection into three groups: under-, ideal, and overcorrection of the paralyzed cord. We also identified superficial injections, indicated by the absence of vocal cord vibration because the filler injected superficially.

Adding to the functionality of our system, we designed HSV that can be recorded separately from DKG. Using Kang's DKG conversion program from HSV playbacks, temporal change of DKG was made by superimposing one to five vertical pixel rows (Figure 3).[7]

RESULTS

Validation of real-time DKG in a vocally healthy participant

We tested the performance of real-time DKG in a normophonic participant. The results are summarized in Table 1. Up to 10 scanning lines can be selected, and DKG can be represented differently according to vertical pixel rows from one to five. The vertical pixel rows mean the number of vertical pixels to form one scanning line.

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