CHAPTER 9

Videokymography: a New High-Speed Method for the Examination of Vocal-Fold Vibrations

Švec J. G., Šram F., Schutte H. K.
Videokymography: a New High-Speed Method for the Examination of Vocal-Fold Vibrations

Jan G. Švec, František Šram, Harm K. Schutte*

Center for Communication Disorders, Medical Healthcom, Ltd.; Rešovská 10/491; 181 00 Prague 8, the Czech Republic (director: Ass. Prof. František Šram, M.D., Ph.D.)

and

*Groningen Voice Research Lab; Department of Biomedical Engineering – Artificial Organs, University of Groningen, Bloemsingel 10, 9712 KZ Groningen, the Netherlands (director: Prof. Harm K. Schutte, M.D., Ph.D.)

ABSTRACT

Videokymography is a new optical high-speed method for investigation of vibrations which was developed especially for examination of vocal-fold vibrations. Videokymography is based on a modified CCD video camera, which is able to work in two different modes: standard and high-speed. In the standard mode the camera works as a normal commercial video camera providing 25 images (50 interlaced fields) per second. In the high-speed mode the camera delivers images from a single selected line with a frequency of almost 8000 line images/s. The successive line images are put below each other, creating a new videokymographic image monitoring vibration of the selected part of the vocal folds in time. A foot switch makes it possible to change instantaneously between the standard and high-speed modes. Ordinary videolaryngoscopic equipment with a powerful endoscopic continuous-light source can be used for the videokymographic examination of the vocal folds. Both the standard as well as high-speed images can be recorded by means of a normal video recorder, which makes the technique cost-friendly.

The method is able to objectively evaluate important parameters of the vocal-fold vibration, such as the open, opening, closing and closed phases of the vibratory cycle, propagation of mucosal waves, left-right differences in phase or amplitude, etc. Videokymography provides more detailed information on voice disorders and considerably enriches laryngostroboscopy. There is no problem for videokymography to evaluate hoarse or unstable voices in which laryngostroboscopy fails. Also, the method is able to reveal structural irregularities on the medial surface of the vocal fold (e.g., sulcus glottidis) which can easily be overlooked in laryngostroboscopy. It is demonstrated how combination of a few laryngostroboscopic and videokymographic images can shortly and efficiently summarize important anatomical, physiological/pathological and vibrational properties of the laryngeal tissues in various patients.

Key Words: videokymography, high-speed imaging, vocal folds, vocal-fold vibration, laryngoscopy, laryngostroboscopy

INTRODUCTION

Since vibration of the vocal folds is crucially important for the resulting quality of voice, its objective evaluation is an essential task for laryngologists and phoniatricians. The vibration of the vocal folds is too fast to be observed by human eye (under normal conditions the frequency is in the range from ca. 70 to 1000 Hz) and it even cannot be registered by a video camera since its image rate is slower: 50 images (or fields, more specifically) per second. In order to visualize vocal-fold oscillation, most frequently a stroboscopic light source has been used, which creates an illusory slow motion of the vocal folds.

Laryngostroboscopy was introduced for the investigation of the vocal folds by Oertel in 1878 (11). Since that time laryngostroboscopy has brought a lot of valuable information on the mechanism of the vocal-fold vibration and successively became the indispensable standard clinical method for the examination of voice. In Czechoslovakia, the process of application and spreading of laryngostroboscopy needs to be credited to Seeman, Sedláčková and
especially to Sovák who published his monograph on laryngostroboscopy in two volumes in 1945 (17, 18).

[Note: Unfortunately, this valuable textbook has not been translated from Czech and remained overlooked in the scientific world abroad. The first internationally recognized textbook on laryngostroboscopy is the monograph of Schönharl (14) which was published 15 years after Sovák (7)]. (See also footnote). Modern laryngostroboscopic systems employ video equipment for registering the stroboscopic images. The newest computer-integrated videolaryngostroboscopic systems make it possible to apply a computer-aided image analysis to evaluation of the vocal-fold vibration and its quantification (9, 10, 12, 13, 24).

The main disadvantage of laryngostroboscopy is that it works properly only with periodic oscillation of the vocal folds. This makes it problematic to laryngostroboscopically evaluate patients with hoarse or breathy voices, as well as patients unable to keep a stable pitch during phonation. When examining these voices there arise illusory, purely stroboscopic effects which can lead to a faulty interpretation of the vocal-fold vibration (7).

The limits of stroboscopy have stimulated a search for other laryngoscopic methods, not limited by the periodicity of the vocal-fold oscillation. In 1970s, a German phoniatrician Gall invented the method of photokymography (2, 3), which was based on a specially modified photographic camera. The camera had a narrow slit/shutter (in front of the film) which moved during the image exposition. The moving slit enabled to record the vibration of the vocal folds on a photographic film. Although the photokymographic images appeared very promising for diagnostical purposes, the system encountered technical problems and has never overcome the stage of a prototype.

The most powerful laryngoscopic systems, which are not limited by the periodicity of the vocal-fold oscillation, use high-speed cameras working at rates more than 1000 images/s. The first high-speed cinematographic system for the examination of the oscillation of the vocal folds was developed in the 1930s in Bell Telephone Laboratories, USA (1). Since that time, the high-speed cinematographic cameras have been explored in a number of studies of the vocal-fold vibration [detailed list of publications can be found, e.g., in (6)]. Recently, the classical high-speed cinematographic systems have been supplanted by digital high-speed imaging systems (4, 5, 8, 23), which present the most powerful devices for investigation and analysis of the vocal-fold vibrations to date. These systems, however, remain rather expensive for most of the hospitals and laboratories, therefore their use is limited to only few specialized research institutes over the world.

**VIDEOKYMOGRAPHY**

In 1994 a research project was carried out at the University of Groningen under the supervision of Prof. Dr. H.K. Schutte, the purpose of which was the development of a new, inexpensive method for examination of various kinds of vocal-fold vibrations which would be suitable for a routine clinical use. As a result of this project Švec designed a new optical method for observation of vibrations – videokymography (16, 20–22). The method was practically realized in cooperation with the Lambert Instruments BV company.

The videokymographic device is based on a specially modified CCD video camera which can function in two different modes – standard and high-speed. The principle is illustrated in Fig. 1.

In the standard mode the camera functions as a normal commercial video camera, registering 50 fields/s (CCIR/PAL TV standard), and it provides a normal laryngoscopic view of the vocal folds. In the high-speed videokymographic mode the camera registers images from a single line of the CCD chip (Fig. 1, left). The reduced amount of spatial data enables to increase the image rate of the camera to almost 8000 line images/s (more specifically 7812.5 line images/s in accordance with the CCIR/PAL TV standard). The successive line images are put below each other and create a new, videokymographic image monitoring the vibration of the selected part of the vocal folds in time (Fig. 1, right). The videokymographic image contains ca. 140 successive line images representing altogether the time of ca. 18 ms.

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**Fig. 1. Two modes of the videokymographic camera. A) the laryngeal image viewed by the standard mode of the camera. The image is composed of horizontal lines. In the videokymographic mode (B) the camera registers images from a single active line at a high-speed image rate. The consecutive line images are put below each other and create a new videokymographic image monitoring the vibratory pattern of the selected part of the vocal folds.**
The standard and videokymographic modes of the camera are used alternately. In practice, the standard mode is explored for finding the place of interest and positioning the active line of the camera to the desired place. After aiming the active line at the selected spot, the camera is instantaneously switched into the videokymographic mode (usually by means of a foot switch). A standard videolaryngoscopic setup is used for videokymography (rigid laryngoscope, light source, video camera, TV monitor). The vocal folds are illuminated by continuous (non-stroboscopic) light. Both the standard as well as the videokymographic video signals can be recorded via a standard commercial video cassette recorder (here it is advantageous, similarly as in videostroboscopy, to use a video cassette recorder capable of providing separate static images of the image fields instead of the interlaced video frames).

MATERIAL AND METHODS
The initial testing phase of videokymography was carried out in 1994 in the Groningen Voice Research Lab in the Netherlands. Two male subjects without voice problems produced various kinds of phonations (normal, breathy, pressed, etc.) which were registered stroboscopically as well as videokymographically (21). A black and white videokymographic CCD camera (Lambert Instruments BV, Leutingewolde, the Netherlands) was connected to a 90° rigid endoscope (type von Stuckrad, R.Wolf, Germany) using a zoom objective/adapter (R. Wolf, type RIWO). A stroboscopic light source (Brüel & Kjaer 4914) was used for stroboscopic examinations, a high-intensity continuous light-source (R. Wolf, AUTO-TCP-Lichtprojektor 5108) was used for videokymography. A Betamax video cassette recorder (SONY model SL-C9ES) was used to record the video signals. Besides the vibrating vocal folds, the vibration of violin strings (20, 22) and the airflow-induced vibration of a membranous slit were also observed in order to test the videokymographic system.

Since 1996 the videokymographic system has been tested clinically in the Center for Communication Disorders, Medical Healthcom, Ltd. in Prague. More than 900 examinations of patients with physiological as well pathological findings have been carried out here. Each videokymographic examination of a patient was preceded by detailed complex phoniatrical examination, including recording of voice and speech in a sound-treated room, investigation of a voice range profile and videolaryngostroboscopy. A videokymographic camera (Lambert Instruments BV, Leutingewolde, NL) and a 90° rigid endoscope (type von Stuckrad, R. Wolf, Knittlingen, Germany) with a lens/adapter (Atmos or Kay Elemetrics 9117) were used for videokymography. A high-intensity (300 W) xenon continuous-light source (R. Wolf Auto LP 5130 or Auto LP/FLASH 5135) was used for illuminating the larynx. A stroboscopic light source (R.Wolf 5021 or Kay Elemetrics 9106), color CCD video camera (Atmos KP-C250AE or Panasonic GP-US502) and a rigid endoscope (90° Lupenlaryngoskop R.Wolf 4450.47 or 70° Kay Elemetrics 9106) with a lens/adapter (Atmos or Kay Elemetrics 9116) were used for laryngostroboscopy. The video images from both types of examinations were recorded using a video cassette recorder (s-VHS Panasonic AG 7355).

Those laryngoscopic, stroboscopic and videokymographic images which best characterized the laryngologic state of the patient were selected from the video recordings. The images were digitized and fed into a PC using a video grabber (AV Master, FAST, Germany). Sequences of consecutive videokymographic images (as in Fig. 8D) were digitized and concatenated by means of a frame grabber ZOB3 using a software OBR v. 3.5 (created and adapted for the videokymographic purposes by VIDIS company, Prague, the Czech Republic). The digital images were further processed and composed together using the software package COREL DRAW! (Figs. 5–8).

RESULTS
Subjects without voice problems:
Fig. 2 shows a stroboscopic image of a male subject without any subjectively reported voice problems. There is a thickened blood vessel, a hemangioma, on

![Fig. 2. Stroboscopic image of male vocal folds as registered by the standard mode of the camera. The horizontal line marks the position of the active line used during the videokymographic recording shown in Fig. 3. (From Švec, J.G., Schutte, H.K.: Videokymography: high-speed line scanning of vocal fold vibration. J. Voice, 10, 1996: 201–205, used with permission).](image-url)
the right vocal fold which did not cause any noticeable problems during phonation. The line in Fig. 2 marks the place which was examined videokymographically. The videokymographic image is given in Fig. 3. It clearly shows open and closed phases of the glottal cycle. An opening movement of the upper margins of the vocal folds followed by the propagation of mucosal waves is visible here. In the closing phase there can be observed the movement of the upper as well as of the lower margins of the vocal folds. Fig. 4 schematically illustrates the most important features of the normal vocal-fold vibration and relates the videokymographic view with stroboscopic images.

**Subjects with voice disorders:**

Four illustrative examples of laryngeal findings in patients are described here, which are documented by characteristic laryngoscopic, laryngostroboscopic and videokymographic images of each patient.

**Patient no. 1 (Fig. 5):** female, age 69. Diagnosis: chronic laryngotracheitis, slight atrophy of the left vocal fold, compensational hypertrophy of the ventricular fold left. There was a tendency towards hyperadduction of the vocal folds. The voice disorder arose 3 years before the examination as a consequence of laryngitis.

Examination results: the voice was perceptually evaluated as hoarse and strained. Laryngoscopy
showed slightly inflamed vocal folds of a pink-grayish color with a smooth, glossy surface. The right vocal fold was without any signs of atrophy, the left vocal fold was slightly atrophic and thinner. Gross mobility of the larynx was undisturbed. Under stroboscopic light, both vocal folds were observed to vibrate in their full length, their oscillations appeared unstable and their amplitudes of vibration were slightly reduced (slightly larger amplitude was observed on the right). Mucosal waves were present bilaterally. There was a posterior triangular glottal gap in the glottal closure (Fig. 5A). The left ventricular fold was bulged into a paramedial position during phonation (Fig. 5B).

Videokymography (Fig. 5D) revealed a prolonged closed phase (ca. 70% of the cycle) as a sign of a slight spasticity. Furthermore, there was found an “S-shaped” course of the glottal closure, which indicates a left-right swinging of the glottis during the closed phase. This gives evidence on phase asymmetry in the vocal-fold vibration. Other videokymographic features visible
in Fig. 5D support the stroboscopic findings: the vibratory amplitude is reduced, the upper margin of left vocal fold shows slightly larger amplitude than that one on the right, mucosal waves are apparent on both the vocal folds. A lower margin is visible on the left atrophic vocal fold during the closing phase. Besides of these findings, there was observed a slightly asymmetrical position of the soft palate which was pulled towards the right side (an evidence of a partial innervation disorder of the soft palate left). The laryngostroboscopic as well as the videokymographic findings lead us to suspect a partial innervation disorder of the larynx at the left side.

**Patient no. 2 (Fig. 6):** female, age 40. Diagnosis: chronic laryngotracheitis, state after debulking a chronic edema on the right vocal fold and removal of a vocal-fold polyp left 2 years before the examination.

Examination results: the voice was perceptually evaluated as hoarse with slight breathiness. Laryngoscopy (Fig. 6C) revealed slight chronic inflammation of the laryngeal (and tracheal) mucosa. The vocal folds were of a pink-grayish color, with broadened vessels. The right vocal fold was atrophic with a thin excavated margin. The left vocal fold was slightly thickened due to a residuum of a chronic edema localized on the upper surface of the membranous part of the fold. At the borderline between the anterior and middle thirds of that vocal fold, there was a small polyp placed slightly subglottaly (Figs. 6B, C). The gross mobility of the vocal folds was preserved. A 3-mm-long synchia was found at the anterior commissure. Under stroboscopic light, both the vocal folds were observed to vibrate in their full length; their amplitude was slightly reduced bilaterally. Glottal closure revealed an insufficiency in the middle third as well as in the posterior third of the vocal fold (Fig. 6A).

Fig. 6D shows a videokymogram of the vibratory pattern of the vocal folds taken at the position marked in Fig. 6A. The glottis remains open through most of the cycle, touching each other only for a short moment, which confirms the stroboscopic finding of glottal insufficiency (causing the slight phonatory breathiness). Light reflexes in the form of diagonal lines reflect mucosal waves propagating bilaterally on the upper surfaces of the vocal folds. A double peak (marked by the arrows in Fig. 6D) reveals a furrow on the medial surface of the right vocal fold (sulcus glottidis). On the basis of this videokymographic finding, the furrow was later discovered also in stroboscopy (see arrows in Fig. 6B).

**Patient no. 3 (Fig. 7):** male, age 70. Diagnosis: partial ankylosis of the cricoarytenoid joint right and deep vocal-fold scarring right (a consequence of a post-surgical complication following removal of a ventricular-fold cyst right 30 years before the examination); laryngeal paralysis left accompanied by ankylosis of the cricoarytenoid joint (after a viral infection 1 year before the examination; accompanied by dysphagia when swallowing fluids).

Examination results: the voice was perceptually evaluated as hoarse, breathy, almost aphonic. Laryngoscopy (Fig. 7A) showed good mobility of the
right arytenoid cartilage in the range from lateral to paramedial position. The left arytenoid cartilage was immobile, tilted ventro-medially, visually crossing the glottal midline. The right ventricular fold was partially mobile up to paramedial position, the left one was immobile and atrophic. A ca. 5-mm-long synchia was found in the anterior part of the vocal folds. The vocal folds were of a pink-grayish color, slightly inflamed, having thin excavated margins with bilaterally delineated furrows. The right vocal fold was slightly diffusely thickened and adducted only in its dorsal half within a restricted range (ca. 2 mm) from the lateral to paramedial position. The left atrophic vocal fold had a thin excavated margin and was immobile, positioned intermedially.

Laryngostroboscopic examination showed a vibration of a thin, partially separated medial part of the mucosa at the middle membranous third of the right vocal fold. The oscillations were irregular of a reduced amplitude. The left vocal fold was vibrating in its full length, except of the most anterior part related to synchia. Its vibration amplitude was reduced, mucosal wave was observed in the medial third of the membranous part of the vocal fold. A wide glottal gap was found during the closed phase (Fig. 7B).

Videokymographic investigation shown in Fig. 7C was done in the posterior part of the glottis (see Fig. 7B for the position). The right vocal fold did not oscillate here, the left vocal fold showed oscillations at a frequency of ca. 120 Hz. A wide glottal gap remained between the vocal folds. Fig. 7D presents a videokymogram obtained from the middle part of the glottis during another phonation. The thin medial margin of the right vocal fold was oscillating here at an irregular frequency, apparently higher than the frequency of ca. 150 Hz observed on the left vocal fold. An irregular vibration with a small amplitude was present on the right ventricular fold. The frequency differences between the vibrations of the two vocal folds and their oscillatory irregularities unveil the origin of the hoarseness in this patient; the wide glottal gap is related to the strong breathy component of the voice.

**Patient no. 4 (Fig. 8):** male, age 69. Diagnosis: state after cordectomy left and deep scarring of the vocal fold right as a consequence of radiation therapy 10 years before the examination; state after successful mastering of ventricular voice.

Examination results: the voice was perceptually evaluated as low-pitched with variable degree of hoarseness—there were recorded occasional aphasis, hoarse phonations with a strong breathy component, as well as phonations with only slight degree of hoarseness. Laryngoscopy (Fig. 8A) showed the right vocal fold with a smooth surface and broadened blood vessels. Gross mobility of the fold was preserved up to paramedial position. On the left side, a structure was left after the cordectomy. The ventricular folds were hypertrophic, concavely bulged. They approximated each other during phonation (Fig. 8B), reached a complete closure and oscillated with an irregular frequency. Signs of mucosal waves were noted at the surfaces of the ventricular folds. The videokymogram in Fig. 8C shows one of the best (least hoarse), relatively high-pitched (frequency ca. 120 Hz), ventricular phonations. Large oscillatory amplitude is apparent here as well as vigorous mucosal waves on the ventricular folds. Slightly worse and perceptually hoarse phonation is shown in Fig. 8D in 4 consecutive videokymographic images. Apparently irregular oscillations of the ventricular folds with small amplitudes are visible here.
DISCUSSION AND CONCLUSION

The developed videokymographic system makes it possible to relatively easily and quickly monitor vocal-fold vibrations. Videokymographic images can be used for an objective evaluation and subsequent analysis of important parameters of the vocal fold vibration (e.g., frequency, amplitude, irregularities, left-right asymmetry, propagation of mucosal waves or duration of the various phases of the glottal cycle such as open, opening, closing and closed phases). These parameters, reflecting the physiologic/pathologic state of the vocal folds, cannot be objectively evaluated by means of videolaryngostroboscopy (especially when the voice is more or less perturbed).

In clinical practice the videokymographic method substantially enriches the diagnostic possibilities of laryngostroboscopy. Laryngostroboscopy provides information on appearance and mobility of the laryngeal structures during vibration and on that basis makes it possible to qualitatively evaluate some of the vibratory features (regularity, shape of glottal closure, etc.). Videokymography complements stroboscopy because it objectively reveals the dynamic behavior of the vocal folds and other laryngeal structures in detail and it can be used for quantification of the vibratory parameters. The advantage of the videokymographic high-speed imaging becomes apparent especially when investigating irregular vocal-fold oscillations such as, e.g., severely dysphonic voices in which the stroboscopic method fails. Videokymography also makes it possible to unveil details such as surface irregularities of the medial margin of the vocal folds which can easily be overlooked in stroboscopy (recall Fig. 6D-sulcus glottidis).

Combinations of the videostroboscopic and videokymographic images, such as those shown in Figs. 5–8, enable to understand the mechanism of a voice disorder in more detail. The combined images provide a more complex view of the anatomical changes as well as of the functional state of the vocal folds. One of the most important advantages of the combination of these examination methods is the simplicity and instructive description of the laryngeal findings by means of the images. The documentation of the selected images makes it possible to arrive at a more detailed diagnosis of voice disorders, to evaluate the progression of the morphologic changes in time, as well as to evaluate the results of voice therapy. It enables to discover minimal organic as well as nonorganic pathologic changes of the vocal folds. Thanks to these merits videokymography appears helpful in laryngologic practice (16, 19), as well as in basic voice research. A considerable advantage of videokymography is its relatively low price since the camera does not require any non-standard recording media and the video signal can be recorded via, e.g., a standard commercially available video cassette recorder.

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FOOTNOTE: An important improvement came from Van den Berg in Groningen, who designed the delta-f generator, which made the use of stroboscopy more practical and applicable in clinical settings. [Van den Berg Jr. A delta-f-generator and movie-adapter unit for laryngostroboscopy. Practica Oto-Rhino-Laryngologica 1959; 21(S):355–363.] (This text was not incorporated in the original Czech version of the paper).

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