KYMOGRAPHIC IMAGING OF THE VOCAL FOLD OSCILLATIONS

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ABSTRACT

Kymographic imaging represents a method of viewing vocal fold oscillations, which is alternative to the routinely used frame-by-frame playback of the video recordings. Instead of video images of the whole vocal folds, in kymography images at only a single line are recorded. The successively recorded line-images are put together to create the resulting kymographic image. This image displays vibratory behavior at the selected part of the vocal folds. The paper briefly reviews four kymographic methods: photokymography, videokymography, videostrobokymography and high-speed digital kymography; and demonstrates the relationship between the kymographic vibratory pattern and the vibratory pattern of the vocal folds known from traditional laryngoscopy. Factors such as the selected position of the active line and the intended type of voice are pointed out to be important in evaluation of the vocal-fold vibratory pattern displayed in kymographic images. Applications in which kymographic imaging has been found helpful are, for instance, evaluation of the microdynamics of the glottal oscillatory cycles, glottal onset and offset, glottal tremor, abduction and adduction speed or measurement of resonance properties of the laryngeal tissues.

1. INTRODUCTION

The vocal fold oscillation crucially influences all the basic qualities of voice – pitch, loudness, as well as the spectrum. Information on the vibratory behavior of the vocal folds is important for many specialties dealing with voice and speech. Various methods have been developed to study vocal fold vibration, the most informative ones, however, are based on laryngoscopic visualization of the vocal folds. Visualization of the vocal folds is a routine procedure used by laryngologists, phoniatricians and speech/language pathologists in patients with voice problems, but it has been crucial also for the basic voice research. Recent standard equipment for the examination of the vocal folds includes a laryngoscope (a special type of an endoscope the tip of which can be placed behind the tongue to provide the image of the larynx), an endoscopic light source, a video camera and equipment for monitoring and recording the video images.

Stroboscopic light flashes have traditionally been employed to visualize the vocal fold oscillations that are otherwise too fast to be perceived with the naked eye. Stroboscopy has been of extraordinary importance for clinicians in that it allows to discover subtle pathologic changes on the vocal folds. The use of stroboscopy, however, is problematic for judging the actual vibratory pattern of the vocal folds, especially when the voice is irregular. An alternative method to stroboscopy is high-speed imaging. In the last decade there has been considerable technological progress during which digital high-speed imaging systems became commercially available for examination of the vocal fold oscillations.

The experience with the stroboscopic and high-speed imaging suggests, however, that the traditional frame-by-frame viewing and analysis is rather difficult and quite lengthy for evaluating the actual vibratory pattern of the vocal folds. For that reason, an alternative viewing of the vocal fold oscillations using “kymographic” images has been employed.

2. KYMOGRAPHIC IMAGING

A direct predecessor of the modern kymographic-imaging used for displaying the vocal-fold oscillations today is the method called “photokymography”, developed by Gall et al. [1]. Gall developed a special camera with a moving slit that allowed recording vocal fold vibration on a photograph (Fig.1). The method demonstrated the capability of providing useful information on the vocal-fold oscillations, but the technical and marketing problems caused the method to remain only in the stage of a prototype.

Figure 1: Photokymography of the vocal folds as developed by Gall et al. [1]. A moving slit is employed as a camera shutter allowing recording the vocal fold oscillations on a photograph.

In 1994 a method called “videokymography” (VKG) was developed by Švec and Schutte [2;3]. The method is based on a special videokymographic camera, which can function in two different modes – standard and high-speed (Fig.2). In the standard mode, the camera provides standard images displaying the whole vocal folds at standard video frame rate (30/25 frames/s in the NTSC/CCIR-PAL TV formats, respectively). In the high-speed mode, the video camera delivers images from only a single line selected from the whole image at the speed of...
approximately 8000 line-images/s. In contrast to photokymography, the measuring line does not move but stays at the same position (e.g., in the middle of the vocal folds). The same principle of displaying the images recorded at a specific line (set at a constant position) over time has been used also in videostrobokymographic (VSKG) as well as digital kymographic (DKG) imaging of the vocal folds.

The kymographic viewing of the vocal fold oscillations was independently introduced also by Isogai as a useful way of evaluating laryngostroboscopic video recordings [4]. In 1999 the method was adapted by Sung et al. [5] and named “videostrobokymography” (VSKG). In videostrobokymography, the individual line-images are taken from the digitized successive stroboscopic video images. The advantage of the method is that it does not require any special high-speed video camera. The disadvantage is that, unlike the high-speed based kymography, it suffers from the stroboscopic limitations and does not allow reliable viewing of irregular vibrations.

Inspired by the development of videokymography, the kymographic display has been applied also as an alternative option for viewing the images recorded with full high-speed digital imaging systems [6,7]. These images have been called “digital kymograms” (DKG) or simply “kymograms”. Demonstrational examples of the full high-speed digital recordings and the software used for processing into digital kymograms have been published on an informational CD-ROM [8]. The full high-speed digital imaging systems present the most technologically advanced, but also the most expensive method for visualization of the vocal fold oscillation available today. The advantage of the high-speed digital kymographic imaging is that the measurement position can be selected from any place of the vocal folds after the recording has been done, while in videokymography the measuring position is selected prior to examination and once the recording has been done it cannot be changed. The line resolution and the image rate, however, are about three times smaller than in the VKG method.

Table 1 summarizes the most important technical parameters of the methods used for kymographic imaging of the vocal folds today. There are advantages as well as drawbacks when these methods are compared. Discussion on some of these topics can be found, e.g., in [6].

3. INTERPRETATION OF THE KYMORPHIC IMAGES

In order to be able to interpret the kymographic vibratory pattern it is useful to compare the kymographic view to more traditional displays of the vocal fold oscillation. In Figure 3, the upper row of sketches depicts eight phases of an oscillatory cycle in the frontal section of the vocal folds, starting with vocal fold opening and ending with a full vocal fold closure. The second row of sketches presents the same eight phases as viewed from above the vocal folds (i.e., view used in laryngostroboscopy and high-speed laryngoscopy). The third main sketch shows the vibration at the middle part of the vocal folds as displayed in kymography.

The kymographic image depicts two cycles of the vocal fold oscillation. The important features are: the open and closed phases of the cycle, the opening phase followed by the propagation of mucosal waves and the closing phase with the visible lower and upper margins of the vocal folds. Besides the vocal folds also the non-vibrating ventricular folds are displayed. The time instances of the eight phases of the two alternative views displayed above are marked in the kymographic image so that the different views can be related to each other.

Figure 3: Schematical drawing of the successive phases of an oscillatory cycle in three alternative views: a) the frontal section of the vocal folds, b) laryngostroboscopy (view from above) and c) kymography at the middle of the vocal folds (line-imaging view from above).
4. FACTORS TO BE CONSIDERED WHEN EVALUATING THE KYMOGRAPHIC IMAGES

In order to interpret the displayed kymographic pattern correctly one has to consider

- the measuring position at which the kymographic image was taken
- the type of voice produced

4.1. Measuring Position

The vibratory pattern displayed in kymographic images is dependent on the measuring position. There are two factors which influence the resulting image:

- position along the glottal axis
- angle with respect to the glottal axis.

In normal cases, the position in the middle of the vocal folds is usually considered to provide the representative vibratory pattern of the whole vocal folds. In case of vocal fold lesions, however, the vibration characteristics generally differ along the glottal axis. The vibratory pattern at the lesion as well as at the positions anterior and posterior to the lesion could reveal useful pieces of information in these cases. The angle of the measuring line is, as a standard, adjusted to be perpendicular to the glottal axis. When using videokymography, the measuring position is adjusted prior to the examination. The longitudinal position is varied by up-down tilting or forward-backward positioning of the endoscope, the perpendicularity of the measuring position with respect to glottal axis is achieved by rotating the camera head on the endoscope. In digital kymographic and videostrobokymographic methods the measurement line can be adjusted as a software option post recording. (e.g., [6-8]).

4.2. Type of voice produced

Human voice disposes of relatively large scale of vocalizations, which are based on different ways of vocal fold oscillations. There are at least three main characteristics of voice one should consider when interpreting the kymographic images:

- phonation pitch
- phonation loudness
- phonation type (e.g., breathy, flow, pressed) and/or the voice register (e.g., vocal fry, modal, falsetto)

Some of the issues related to the variability of kymographic vibratory pattern of the vocal folds are described in [3;6]. Ideally the whole frequency and dynamic range should be examined in order to find out the variability of the vibration of specific vocal folds. Usually, however, there is only limited time available for the examination. Therefore phonations at comfortable pitch and loudness are mostly targeted for kymographic imaging.

5. THE APPLICATION OF KYMOGRAPHIC IMAGING IN VOICE

Kymographic imaging is used for viewing the dynamic behavior of the laryngeal tissues. Depending on the type of method used, some of the applications are, for instance:

- evaluation of the microdynamic features of the individual oscillatory cycles of the vocal folds [3;9]
- analysis of glottal onset and offset [10]
- evaluation of the velocity of the abductory and adductory movement of the vocal folds [11]
- studying vocal tremor [7]
- measuring resonance properties of the laryngeal tissues [12]
- imaging the mechanism of coughing

Figure 4 shows videokymographic images recorded in patients with various voice disorders. The images reveal different microdynamic features of the vocal-fold-oscillatory cycles and the potential of kymographic imaging being useful in clinical practice. The microdynamic features that can be evaluated in kymographic images of the vocal fold oscillations are, for instance:

- interference with mucus and ventricular folds
- glottal closure duration (closed quotient)

<table>
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<tr>
<th>Method</th>
<th>Technical features</th>
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<tbody>
<tr>
<td>Videostroboscopy / videostrobokymography</td>
<td>Resolution: 720x486/768x576 pixels (full NTSC/PAL) at 30/25 frames/s, recording time up to hours, images in color, stroboscopic light required</td>
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<tr>
<td>Videokymography</td>
<td>Resolution in standard mode: 720x486/768x576 pixels (full NTSC/PAL) at 30/25 frames/s; resolution in high speed mode: 720x1/768x1 pixels at 7875/7812.5 line-images/s (NTSC/PAL); recording time up to hours, kymographic recording divided into video fields - segments of ca. 15/18 ms duration (NTSC/PAL), images not in color, continuous high-intensity light required</td>
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<tr>
<td>Full digital high-speed imaging systems / high-speed digital kymography</td>
<td>Resolution: 256x256 pixels for rates up to 2000 frames/s; (the spatial resolution decreases with increasing frame rate when above 2000 frames/s), recording time limited to seconds, images not in color (in the standard systems), continuous high-intensity light required</td>
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Table 1: Technical features of the modern systems used for the kymographic imaging of vocal-fold oscillations
6. DISCUSSION AND CONCLUSIONS:

Kymographic imaging provides valuable information on the dynamic behavior of the laryngeal tissues that is not so clearly distinct in the classical frame-by-frame viewing. The information can be used in basic research, vocal fold modeling, as well as in clinical practice. Current research focuses, e.g., on mapping the variability of the oscillations of the vocal folds in normal as well as pathologic cases and on establishing criteria for the evaluation of kymographic images. The first results suggest that kymographic imaging could be useful, for instance, in evaluating the results achieved by phonosurgery. An important further step is relating the dynamic features of the vocal folds displayed in kymographic images to the viscoelastic properties of the vocal folds. Specifying this relationship is essential for a more profound understanding of the mechanism of vocal fold oscillations and can be helpful also in directing the treatment of vocal disorders (phonosurgical or conservative) more directly towards the cause of the problem.

7. ACKNOWLEDGMENTS:

The research has been supported by the Grant Agency of the Ministry of Health of the Czech Republic, Project IGA MZ ČR 6130-3 and by the National Institutes of Health, USA, grant number DC RO1 04224-01.

8. REFERENCES