Investigation of Flexible High-Speed Video Nasolaryngoscopy

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Summary: Objective. High-speed videolaryngoscopy is widely used in voice practices as a complement to videostroboscopy, especially when it is desired to visualize asymmetric and nonperiodic vocal fold vibration or voice onset and offset. Because of the requirement for greater illumination at higher frame rates, the high-speed exam is usually performed with a rigid transoral laryngoscope. Although it is possible to obtain color high-speed video images with a flexible fiberoptic nasoendoscope, the results are often disappointing because of the inability to provide adequate lighting inside the larynx. This paper will present the results of a systematic exploration of tools and techniques to optimize the image brightness of flexible color high-speed videolaryngoscopy exams using the KayPENTAX Model 9710 Color High-Speed Video (CHSV) System.

Methods. The KayPENTAX CHSV System was used with three PENTAX flexible fiberoptic nasolaryngoscopes and a new supplemental light fiber bundle to perform high-speed examinations of healthy vocal folds. Variables of the investigation included camera frame rate, camera sensitivity (color head versus black-and-white head), optics (camera lens focal length), light coupling, nasoendoscope outer diameter, and endoscopy technique (visually perceived distance of the distal tip of scope from the glottal plane).

Results and Conclusions. The manipulation of camera gain, the proper selection of lens coupler focal length, and the adjustment of scope distal tip distance from the glottal plane were found to be most effective for optimizing image brightness, whereas the supplemental light fiber bundle provided minimal benefits. Other factors considered include patient comfort, practicality, and ease of use by the clinician.

Key Words: Laryngeal high-speed videoendoscopy–Flexible fiberoptic nasolaryngoscopy–Color–Supplemental light fiber–Vocal fold vibration.

INTRODUCTION

Laryngeal high-speed videoendoscopy (HSV) is a complement to videostroboscopy that is used by both researchers and clinicians to investigate vocal function, especially when it is desired to visualize aperiodic or irregular vocal fold vibration[1]; asymmetric vibration, vocal tremor and spasms, rough voice, diplophonia, or other laryngeal or pharyngeal sources of vibration[2]; and phonatory gestures such as voice onset and offset.[3] A 70° or 90° rigid scope, which carries more light fiber bundles than a flexible fiber optic nasolaryngoscope, is often used with HSV cameras in order to provide better illumination of the laryngeal and pharyngeal anatomy. For some clinical HSV studies, however, a flexible nasolaryngoscope is more suitable than a rigid transoral scope. A number of studies appearing recently in the literature on the fiber-optic high-speed investigation of singing gestures, natural and humming phonation, and the effects of throat clearing confirm that high-speed video imaging of the larynx through the fiber-optic laryngoscope would be beneficial.[4–9] Monochrome camera sensors were used in all of these recent flexible HSV studies, and the video frame rates ranged from 4,000 frames per second (fps) to 20,000 fps. The ability to capture color HSV images is useful when it is desired to image the effect of tissue irritation and lesions on vocal fold vibratory function. Two HSV systems that were commercially available starting in 2006 for about a decade, one from Richard Wolf Medical Instruments Corp. and one from KayPENTAX, came standard with color cameras, but temporal resolution with these systems was limited to about 2,000–3,000 fps for adequately bright video images with the color head. Shaw and Deliyski (2008) have suggested that 2,000 fps may not be adequate for evaluating mucosal wave characteristics at fundamental frequencies above 200 Hz,[1,10] so the usefulness of color video images at low frame rates is limited. During our tenure at KayPENTAX, we sought to maximize the frame rate at which usable, adequately bright color video images could be obtained with the KayPENTAX Color HSV System, and we have compiled a list of adjustments that can be made to optimize image brightness.

In addition to the challenge of providing adequate illumination in the laryngeal cavity at frame rates of 2,000 fps or more, there are other technical challenges that need to be solved or optimized in order to get adequate high-speed video imaging through an existing fiber-optic-based endoscope. These include proper selection of the lens coupler focal length, proper camera software settings (such as gamma, brightness, contrast, and electronic gain), and distance of the endoscope distal tip from the glottal plane during the endoscopic examination. The use of an auxiliary light source was also explored, with ease of use and patient comfort as the forefront considerations. This paper presents the results of our systematic exploration of how to obtain the best flexible high-speed color images with the KayPENTAX (Lincoln Park, NJ) Model 9710 Color High-Speed Video system using simple techniques and readily available equipment.

Note that the term *laryngeal high-speed videoendoscopy*, and the acronym *HSV*, will be used throughout this paper based on

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the recommendations of Deliyski et al[11] for a concise and specific means of referring to the vocal fold vibration imaging modality considered herein.

MATERIAL AND METHODS

Equipment

The Model 9710 Color High-Speed Video (CHSV) system (KayPENTAX), based on the Photron FASTCAM MC2 color camera head and processor (Photron USA, Inc., San Diego, CA), was used for this investigation. All Photron cameras come with the *Photron FASTCAM Viewer* (PFV) software; in addition, the CHSV System includes the proprietary KayPENTAX recording software application, which simplifies the camera user interface but also eliminates some useful adjustments, such as gamma, brightness, contrast, and color temperature. The CHSV System has been discontinued and is no longer available from PENTAX Medical, but the FASTCAM MC2 camera can still be purchased from Photron for the time being.

The primary light source included with the CHSV System is the KayPENTAX Model 7152A 300-W Xenon Light Source. HSV exams were obtained with three flexible fiberoptic nasolaryngoscopes: the FNL-7RP3, the FNL-10PR3, and the FNL-15RP3 (PENTAX Medical, Akishima, Japan); see Table 1 for the scope insertion tube diameters and other parameters that are of interest to this study. A supplemental light fiber bundle, described later in this section, was used with the FNL-15RP3.

Subject

The subject for this investigation was an adult male, 51 years old (the author), with a history of type I sulcus with reduced mucosal wave on the left vocal fold, mild hyperemia to the interarytenoid area with pachydermia, and mild reflux laryngitis, diagnosed by stroboscopy laryngoscopy examination by an ENT doctor. These conditions were conservatively managed using voice therapy and reflux therapy subsequent to the time of the video exam recordings used for this study. The subject complained of hoarseness at the time of these exam recordings but was otherwise vocally healthy. The author passed the nasolaryngoscopes on himself to obtain the video data.

Methods

A systematic investigation of the effects of adjusting the camera frame rate, changing the lens coupler focal length, adjusting camera software parameters (gain, brightness, shutter speed), changing nasoendoscope outer diameter, experimenting with a supplemental light fiber bundle and additional light source, and adjusting the distance from the distal tip of the endoscope to the glottal plane is now described below.

TABLE 1.
Flexible Nasolarygoscope Parameters

Model Number	Distal Tip Diameter (mm)	Working Length (mm)	Channel Diameter (mm)	Angle of View (°)
FNL-7RP3	2.4	300	N/A	75
FNL-10RP3	3.4	300	N/A	75
FNL-15RP3	4.8	300	2.2	75

Color HSV camera head frame rates, shuttering, and light sensitivity

With the Photron FASTCAM MC2, useable frames rates *in vivo* range from 2,000 fps and 3,000 fps for color images, 4,000 fps in either color or black and white, and 5,000 fps and 8,000 fps in black and white only. The maximum frame rate of 10,000 fps can be used to obtain black and white images outside the body, for example of excised larynges, with adequate ambient lighting.

Shutter speed can be set from 1/(frame rate), designated 1.0x in the KayPENTAX CHSV software, to 1/(10 × frame rate) or faster, so that the actual time the sensor is exposed to light can be reduced to microseconds or less. Increasing the shutter speed reduces blur due to motion, but images are also less bright; therefore the 1.0x setting is generally recommended.[12] All CHSV exams obtained for this study used a shutter speed of 1/(frame rate), selectable as 1.0x in the KayPENTAX recording software application.

Camera light sensitivity is reported for the MC2 using the ISO Ssat method 12232, where Ssat is the saturation-based speed that produces the maximum valid (not clipped or bloomed) camera output signal.[13] For the MC2, the specified sensitivities are ISO 3200 for the monochrome (black and white) head and ISO 1600 for the color head. The intrinsic difficulty of using such a slow sensor (at least by today's standards) at frame rates of 2,000 fps or more is that either the laryngeal cavity must be illuminated with a light source other than what is available through a fiber-optic laryngoscope or the scope tip must be extremely close to the glottal plane in order for enough reflected light from the vocal folds to hit the sensor. Because passing the scope tip extremely close to the vocal folds can be difficult to achieve with many patients, additional adjustments and optimizations in hardware and software were investigated as described in the remainder of this section. However, passing the scope tip as close to the vocal folds as possible should be considered when it is feasible to do so.

Camera lens coupler focal length

The focal length of an optical system is a measure of how strongly the system converges or diverges light. The focal length and the lens magnification are related parameters. A longer focal length lens provides higher magnification and a narrower angle of view. Conversely, the shorter the focal length of a lens, the lower the magnification and the wider the angle of view. The wider angle of view allows more light to reach the camera sensor, thus providing a brighter image. A competing consideration is that a longer focal length lens produces a larger image for the same spatial resolution, which translates into finer details of the structures being observed. However, a shorter focal length can provide more magnification because the subject can be brought closer to the lens and still remain in focus. Two lens couplers have traditionally been sold for use with the CHSV System, the KayPENTAX Model 9118B variable-focus "Zoom" lens, with adjustable focus from 22 to 37 mm (Precision Optics Corporation [POC], Gardner, MA), and the Model 9703, with a fixed focal length of 20 mm,