the stroboscopically lighted portions of the successive waves are fused visually.[15] This phenomenon is known as the persistence of motion, and it is the principle behind film projection. The slow motion effect is created by having the stroboscopic light desynchronized with the frequency of vocal fold vibration by approximately 2 Hz. When vocal fold vibration and the stroboscope are synchronized exactly, the vocal folds appear to stand still, rather than moving in slow motion (Figure 4–7). In most instances, stroboscopic approximation of slow motion provides all the clinical information necessary. However, in some patients

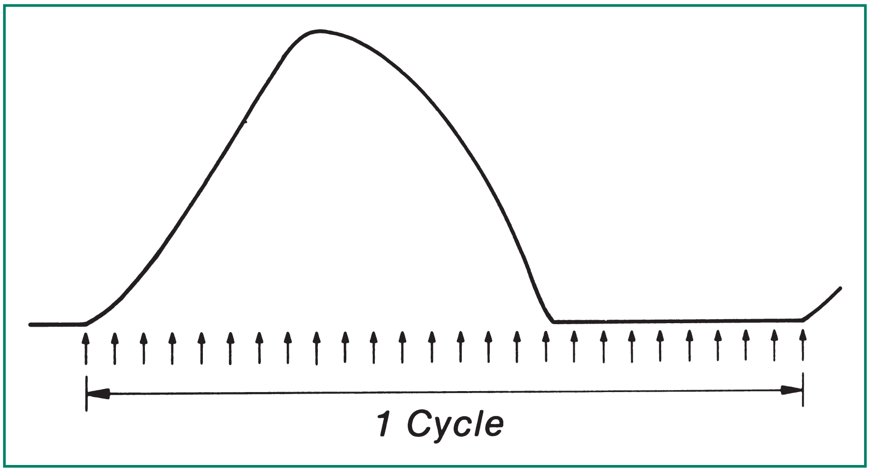


Figure 4–6. The principle of ultrahigh-speed photography and high-speed video. Numerous images are taken during each vibratory cycle. This technique is a true slow motion representation of each vocal fold vibration. (From Hirano M. *Clinical Examination of the Voice.* New York, NY: Springer-Verlag; 1981;55, with permission.)

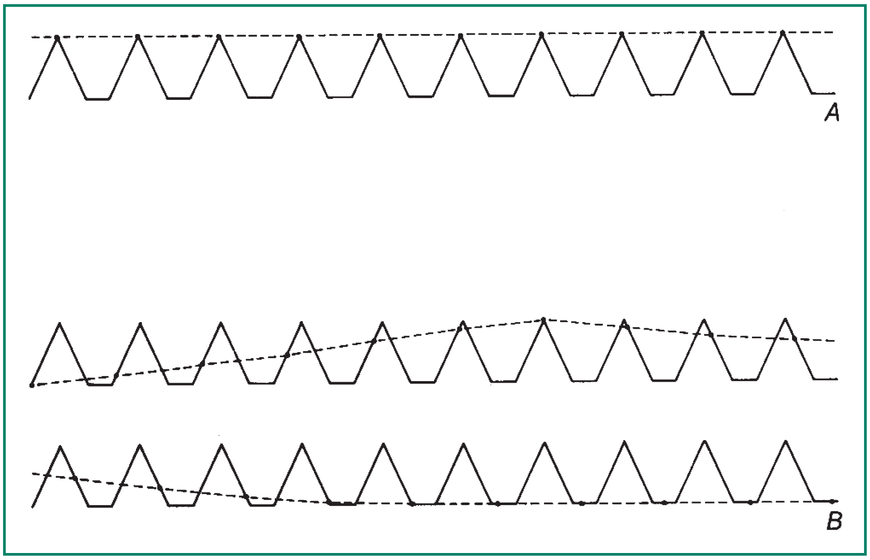


Figure 4–7. The principle of stroboscopy. The stroboscopic light illuminates portions of successive cycles. The eye fuses the illuminated points into an illusion of slow motion. If the stroboscope is synchronized with vocal fold vibration (**A**), a similar point is illuminated on each successive cycle and the vocal fold appears to stand still. If slightly desynchronized (**B**), each cycle is illuminated at a slightly different point, and the slow motion effect is created. (From Hirano M. *Clinical Examination of the Voice*. New York, NY: Springer-Verlag; 1981:49, with permission.)

with aperiodic vocal fold vibration, videokymography or high-speed video may be required.

The stroboscope is also extremely sensitive in detecting changes caused by fixation from small laryngeal neoplasms in patients who are being followed for leukoplakia or following laryngeal irradiation. Recording and storing stroboscopic videos has become invaluable for later reevaluation by the laryngologist, or by other physicians. A relatively standardized method of subjective assessment of videostroboscopic pictures is in wide clinical use,[16–18] facilitating comparison of results among various physicians and investigators.

Laryngeal stroboscopy is not a new technique. However, poor camera light sensitivity limited its use for many years. Improvements in laryngeal stroboscopes and lowlight cameras provided instrumentation practical for clinical use by the mid-1980s. When necessary, it can be supplemented with other techniques, as discussed below. Stroboscopic light was used initially to evaluate the larynx by Oertel in 1878.[19] Since that time, many investigators have recommended the technique, and numerous equipment designs have been tried, only some of which are referenced in this chapter.[20–119] Stroboscopy was adopted earlier in Europe and Japan than in the United States. Various initial shortcomings prevented its routine inclusion in the otolaryngologist's office. For many years, the only equipment available was expensive and cumbersome, and it provided insufficient illumination. In addition, there was no easy way to record the images. In the 1980s, technological improvements resulted in stroboscopes that provided light bright enough to produce acceptable video recordings through a flexible fiberoptic nasolaryngoscope utilizing inexpensive video equipment, and technology has improved markedly since then. In the past several years, such equipment has been used routinely by nearly all laryngologists who specialize in voice disorders.

Since 1999, we have used a KayPENTAX System (formerly Kay Elemetrics, now PENTAX Medical [Montvale, NJ]) (RLS9100B, Figure 4–1). This system is set up to store digital videos on a separate hard drive (KayPENTAX 9200C). The digital system has many advantages, including the ability to access previous examinations almost instantaneously, and the ability to display them on a split screen so that they can be compared easily with the current examination. In addition, it has a built-in program for generating reports, and many other useful features (Figures 4–8 through 4–12). More recent high-definition versions may offer some advantages, but in current systems, the somewhat improved image quality is apparent during acquisition but not as much during playback.

Our routine stroboscopy protocol has been described in previous publications.[13,14] In virtually all cases, we evaluate patients with both flexible and rigid endoscopes at the time of initial assessment. We routinely use a PENTAX charge-coupled device ("distal chip" or "chip tip") scope (PENTAX VNL 1170K). The flexible laryngoscope permits evaluation and documentation of laryngeal motion during natural speech tasks, without tongue restriction. This allows assessment of laryngeal posture during speech and singing, fairly good assessment of vibratory margin activity during normal phonatory activities, and good assessment of laryngeal motion during numerous tasks such as whistling, whispering, rapid speech repetition, and others. We have the patient repeat the spoken and sung maneuvers in his or her native language, if it is not English. We also determine how much time he or she speaks his native language vs foreign languages, and we try to determine visually under what circumstances voice production appears best. Laryngeal telescopes provide better optical images and higher resolution, and they are used routinely for detailed assessment of vibratory margin motion. In spite of the quality of the images from distal chip endoscopes, they have been found to underrepresent certain vocal fold pathologies even when compared to standard fiberoptic scopes.[120,121] Examination with a rigid telescope, with videostroboscopic analysis, remains a more accurate diagnostic tool than either method of flexible examination for identifying structural pathology of the vocal fold.[120–122] We generally use a 70° telescope, although we also have 90º telescopes available because a few patients find them easier to tolerate.

Our protocol begins with flexible laryngoscopy. The patient is asked to state his or her name and the date of the examination. He or she is asked then to count from 1 to 10, to count again from 1 to 10 in a higher-pitched voice, to count from 1 to 10 in a whisper, and to repeat these maneuvers in his or her native language, if it is not English. These maneuvers, and those discussed in the rest of this paragraph, are designed to evaluate laryngeal biomechanics. This is accomplished best by flexible laryngoscopy. If there is supraglottic compression and the vocal folds are difficult to visualize during spontaneous phonation, but supraglottic posture becomes normal and vocal folds are seen easily when counting at a slightly higher pitch, then the observer has evidence that the patient phonates habitually at a pitch that is lower than desirable. This information is helpful to the speech-language pathologist in planning treatment.

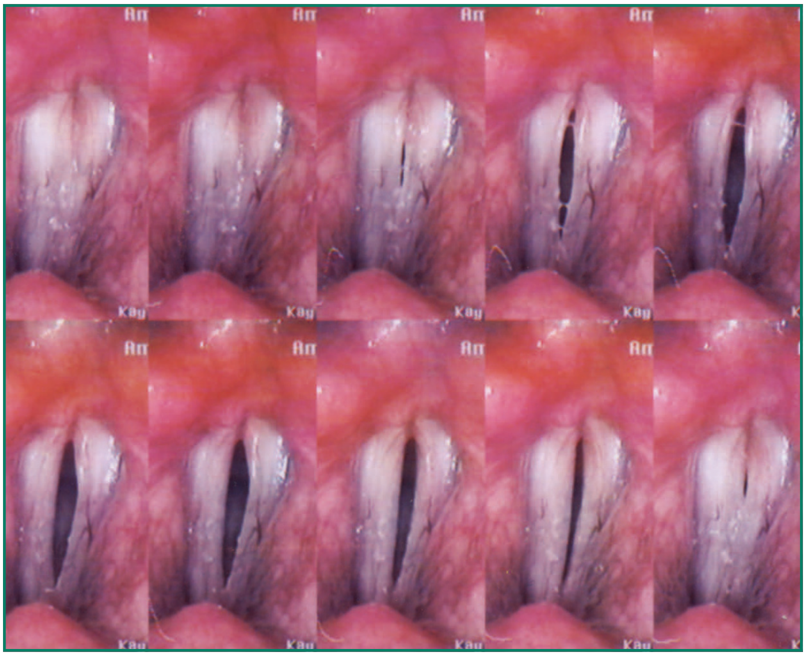


Figure 4–8. Videoprint from the KayPENTAX stroboscopy system (RLS9-100B [PENTAX Medical, Montvale, NJ]). This special feature automatically captures the vocal folds at 36° intervals and prints 10 images (360°), simulating the behavior of a complete glottic cycle. This feature can be very helpful in illustrating asymmetries.

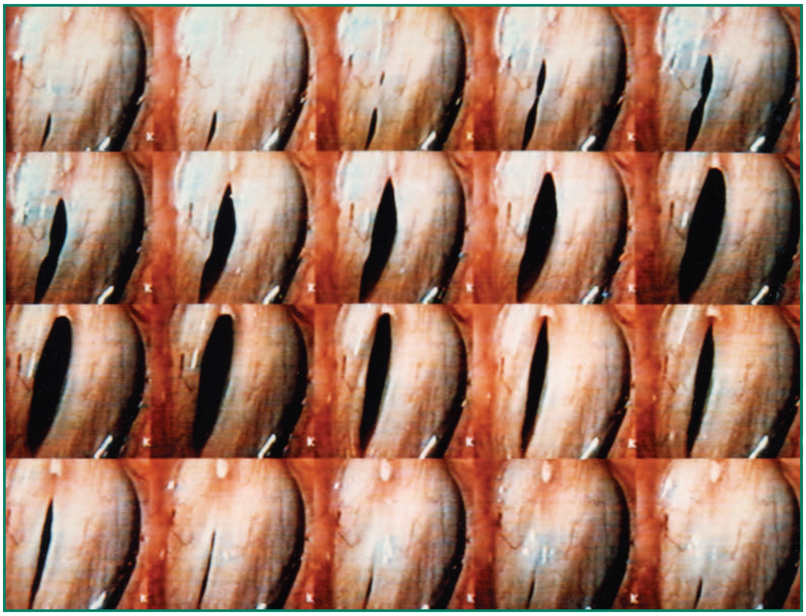


Figure 4–9. The computer can automatically provide images at 18° intervals, printing 20 images to simulate the behavior of a complete glottic cycle in greater detail.

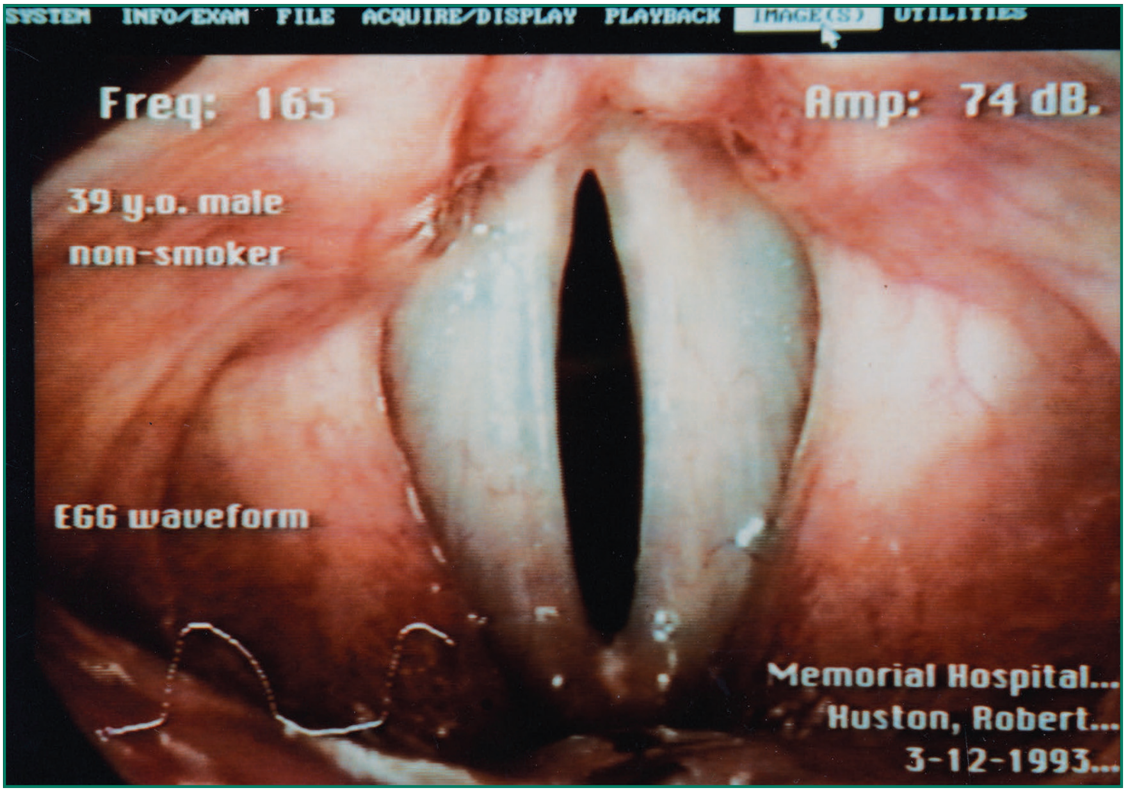
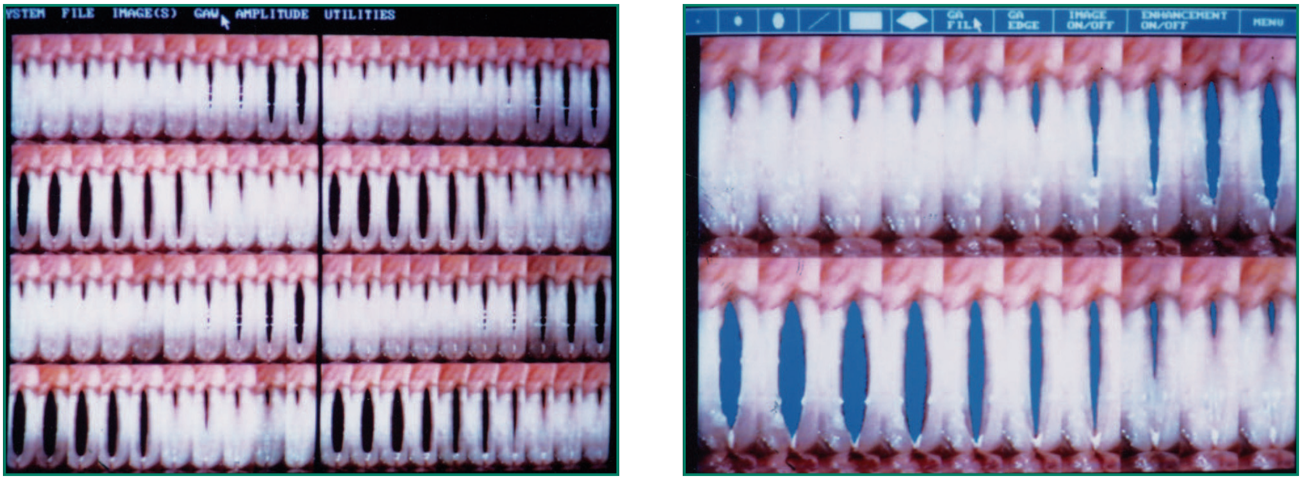


Figure 4–10. The computer capabilities allow labeling of videoprints and automatically provide superimposed EGG display.



A

B

Figure 4–11. A. In the digital analysis program, 80 images representing 4 complete glottic cycles are taken from a stroboscopy recording. **B.** An edge detection algorithm such as the one shown above is used to calculate the area of the glottis and fill it with a contrasting color. The automatic selections can be modified by the user using the computer mouse.

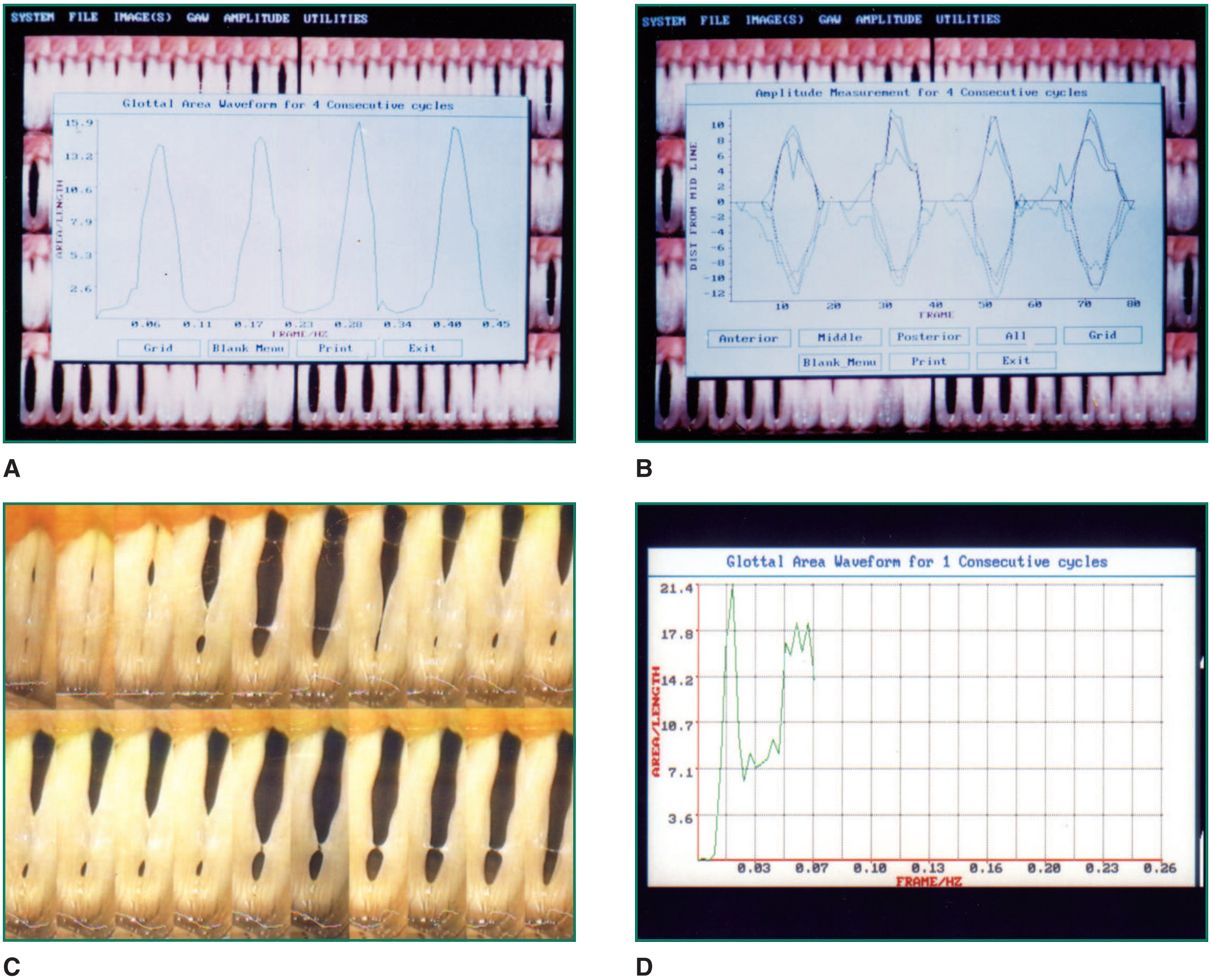
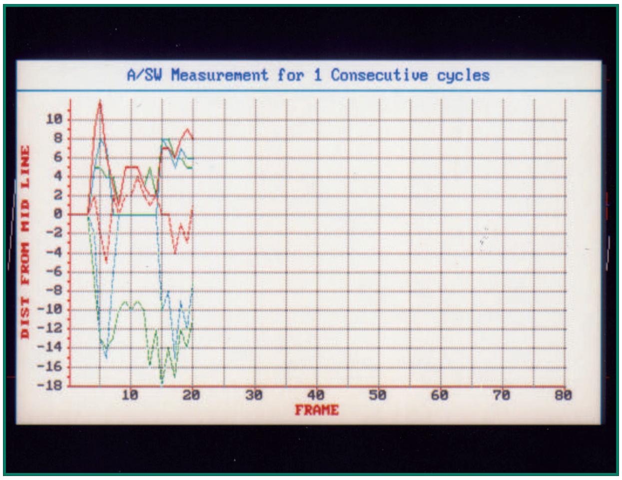
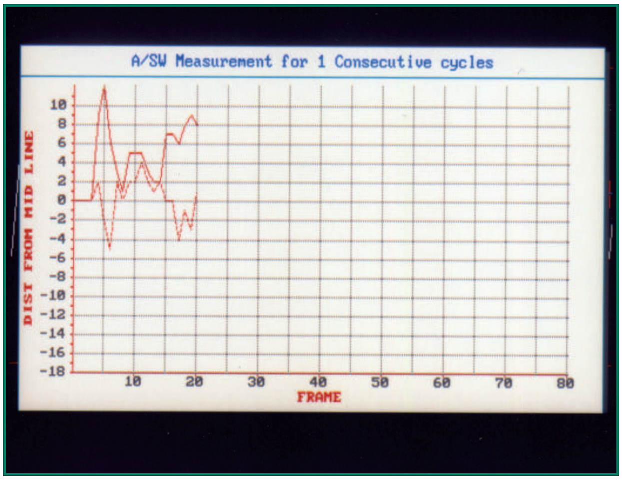


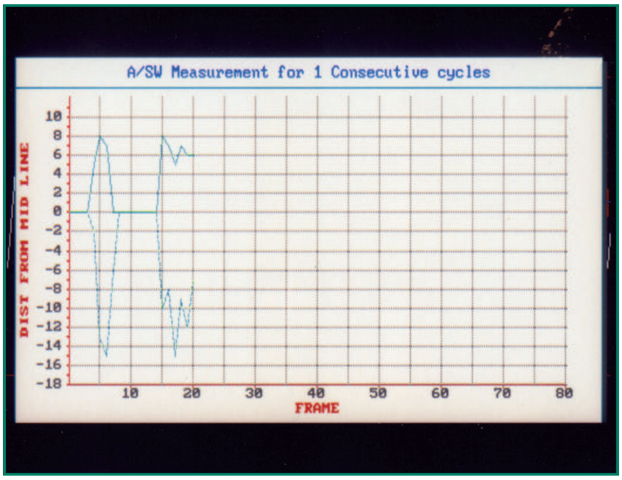
Figure 4–12. A. The digital analysis program allows determination of the glottal area waveform (GAW) as shown above. This is a graphic representation of glottal area changes during 4 cycles of phonation. **B.** An amplitude/symmetry waveform (A/SW) may be even more useful. This represents the excursion at 3 locations (anterior, middle, and posterior) of each vocal fold during the glottal cycle. These are plotted as mirror images and permit assessment of each vocal fold separately, as well as comparison of one vocal fold with the other. **C.** Twenty images, representing one glottic cycle, in a patient with vocal fold cysts. **D.** Glottal area waveform of same glottic cycle. *(continues)*



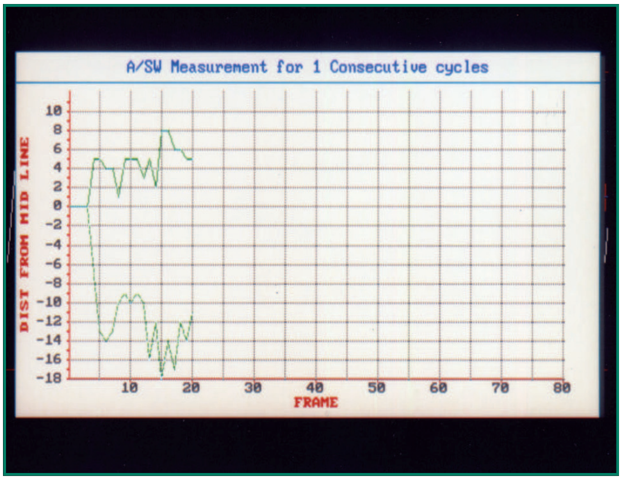
E



F



G



H

Figure 4–12. *(continued)* **E.** Amplitude/symmetry waveform of the same glottic cycle. **F.** A/SW measurement for anterior portion of the vocal fold, graphed separately. **G.** A/SW measurement for middle portion. **H.** A/SW measurement for posterior portion.

It should be noted that simply advising the patient to try to raise his or her pitch is inadequate, as is therapy that uses attainment of "optimal pitch" as the primary focus of voice modification. However, when expert therapy has been completed (as described elsewhere in this book), laryngeal appearance during speech, and habitual pitch, improve in most cases. Biomechanical assessment also includes other maneuvers to assess techniques of voice use and to identify even subtle movement disorders such as mild superior laryngeal nerve paresis, which may underlie other voice problems and must be detected in order to plan optimal treatment. The patient is asked to whistle Yankee Doodle, to slide slowly from lowest to highest pitch and then to slide down; to sniff several times; to alternate rapidly a sniff with the vowel /i/ several times; to repeat several times /i/-/hi/-/i/-hi/-/i/-/hi/; to repeat /pa/-/ta/-/ka/ several times; to sing Happy Birthday; to sing a song or scale, or to speak lines, to demonstrate the patient's problem, if appropriate, and to sustain /i/. Strobovideolaryngoscopy is performed initially with a flexible laryngoscope. The findings are not as detailed as those obtained later with the rigid telescope, but they are helpful for several reasons. First, they permit visualization of vocal fold motion with the larynx in normal posture, rather than with the tongue protruded and being held. Second, they provide a more accurate assessment of posterior glottic opening than can be obtained during rigid endoscopy. We have observed this phenomenon, as have Sodersten and Lindestad.[115,117,122] However, it should be remembered that an open posterior glottic gap is not necessarily abnormal. Third, in the rare patient whose gag reflex or anatomy precludes visualization with a rigid telescope, flexible images may be the only stroboscopic views that can be obtained. Flexible stroboscopic images are obtained with the vocal folds moving at the usual simulated, slow speed created by the stroboscope, at slower speed, and with the stroboscopic light adjusted so that the vocal fold should appear to stand still (to test periodicity). The flexible laryngoscope is removed when this portion of the examination has been completed, and a rigid laryngoscope is used. The patient is asked to phonate /i/ at various frequencies and intensities. The tip of the stroboscope is brought as close to the vocal folds as possible, usually within the laryngeal inlet. With an appropriate size camera lens, the vocal folds should fill the monitor screen. The vocal folds should be observed not only at a 90° angle from directly above the larynx, but also tangentially with the stroboscope moved to each side and angled toward the vibratory margin. This maneuver provides a better 3-dimensional perspective of the vocal fold edge.

We use a standardized method of subjective assessment of strobovideolaryngoscopic images, as proposed by Hirano et al.[16–18] Characteristics that are evaluated include fundamental frequency, symmetry of movements, periodicity, glottic closure, amplitude of vibration, mucosal wave, and the presence of nonvibrating portions of the vocal fold. Other findings such as masses or sulcus vocalis are documented. In addition, objective frame-by-frame analysis is possible with inexpensive computer equipment or the analysis system built into the PENTAX stroboscopy system software.

With practice, perceptual judgments of stroboscopic images provide a great deal of information. However, it is easy for the inexperienced observer to draw unwarranted conclusions because of normal variations in vibration. Vibratory behavior depends on fundamental frequency, intensity, and vocal register (Figure 4–13). For example, failure of glottic closure occurs normally in falsetto phonation. So, if patients are examined only during phonation on a high-pitched /i/ (as is done during routine indirect laryngoscopy with a mirror), virtually everyone will have failure of glottic closure. Consequently, it is important to be familiar with physiologic variations in vocal fold behavior and to examine each voice under a variety of conditions. Fundamental frequency can be influenced by various vocal fold parameters. For example, fundamental frequency is increased with increasing vocal fold tension or stiffness, increased subglottal pressure, or a shortened length of vibrating vocal fold. Fundamental frequency (F_0) is decreased as vocal fold mass increases. More unusual normal variations also may be seen, even in advanced voice professionals.[115,116]

Symmetry is assessed by observing both vocal folds simultaneously. In a trained voice, they are mirror images, opening with the same lateral excursions (symmetry of amplitude) and mirror-image waves

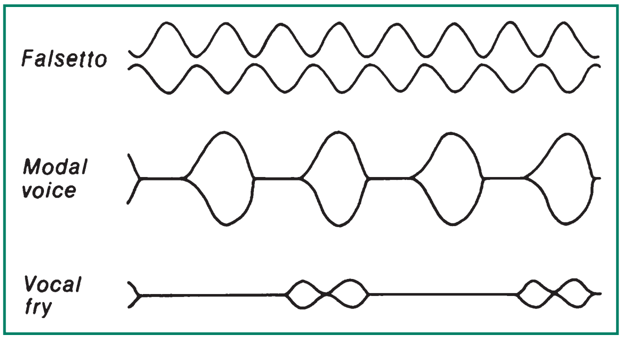


Figure 4–13. The normal vibratory pattern of vocal folds. (From Hirano M. *Clinical Examination of the Voice*. New York, NY: Springer-Verlag; 1981:48, with permission.)