The Human Voice

How the voice works was largely unknown until modern technology became available. New instruments are now improving the care and treatment of the voice

by Robert T. Sataloff

Twenty years ago the human voice was a mystery. Little was known about how it works or how to care for it, despite centuries of fascination with the voices of singers and actors and the crucial importance of vocal communication to society. Literature on voice medicine, and particularly on the care of the professional voice, was scarce. In the few papers that did exist, there was scant emphasis on how the voice worked.

The state of therapy was equally weak. Nonsurgical treatments of benign vocal-fold problems were controversial, and the surgery available involved vocal-cord stripping. (Specialists replaced the term "cord" about 10 years ago with the more descriptive term "fold.") This procedure ripped away the superficial layers of the vocal fold under the assumption that healthy tissue would grow to replace the unhealthy tissue. Unfortunately, many patients ended up permanently hoarse, although their vocal folds afterward looked normal.

Since that time, a new medical subspecialty has emerged. Spurred by interest in the problems of professional singers and actors, scientific and technological advances have raised the standard of care for all voice patients. These improvements were made possible by interdisciplinary collaborations among professionals, who, at first, barely spoke the same language. The Voice Foundation, which was established by physician Wilbur James Gould of New York City to promote such interactions, held its first symposium in 1972 and brought together laryngologists, voice scientists, speech pathologists, singing and acting teachers and performers. The exchange of ideas at that meeting led to new collaborations, new directions in research and many major advances.

Today, 20 years later, it is possible for a singer with a few "lost notes," a governor running for president, a salesperson whose voice is weak, a smoker with a tumor or anyone else with a voice complaint to get sophisticated medical attention. That care is a result of the growing understanding of how the voice works.

The vocal mechanism involves the coordinated action of many muscles, organs and other structures in the abdomen, chest, throat and head. Indeed, virtually the entire body influences the sound of the voice either directly or indirectly. For grasping the vulnerabilities of the vocal tract, a brief tour of this complex, delicate mechanism is necessary. The first stop, and the best-known part of the mechanism, is the larynx, or voice box.

The larynx has four basic anatomic components: a cartilaginous skeleton, intrinsic muscles, extrinsic muscles and a mucosa, or soft lining. The most important parts of the laryngeal skeleton are the thyroid cartilage, the cricoid cartilage and the two arytenoid cartilages. The extrinsic muscles connect these cartilages to other throat structures; the intrinsic muscles run between the cartilages themselves.

One pair of intrinsic muscles extends from the arytenoid cartilages to a point inside the thyroid cartilage, just below and behind the Adam's apple. These thyroarytenoid muscles form the bodies of the vocal folds; the space between them is the glottis. The vocal folds are normally the source of the human voice.

The intrinsic muscles can change the relative positions of the cartilages and pull them through a range of motions. These changes alter in turn the shape, position and tension of the suspended vocal folds. The cricothyroid muscle, for example, participates in the control of pitch by increasing the longitudinal tension (stretching) of the vocal folds.

The extrinsic muscles, also known as the strap muscles of the neck, raise and lower the laryngeal skeleton. The resulting accordion effect also changes the angles and distances between the cartilages and alters the resting lengths of the intrinsic muscles. The larynx has a natural tendency to rise and fall as the pitch of the voice ascends and descends. Such large adjustments in position, however, interfere with the fine control over the vocal folds that is essential for smooth vocal quality. For that reason, classically trained singers are generally taught to use their extrinsic muscles to maintain the laryngeal skeleton at a fairly constant height regardless of pitch. This technique enhances a unified vocal quality throughout a singer's range.

The soft tissues lining the larynx are much more complex than had been thought. The mucosa forms the thin, lubricated surface of the vocal folds that makes contact when they are closed. The mucosa overlying the vocal folds is different from that lining the rest of the larynx and respiratory tract: it is stratified squamous epithelium, which is better suited to withstand the trauma of vocal-fold contact.

The vocal fold is not a simple muscle covered with mucosa. In 1975 physician Minoru Hirano of Kurume, Japan, identified five distinct tissue layers in the

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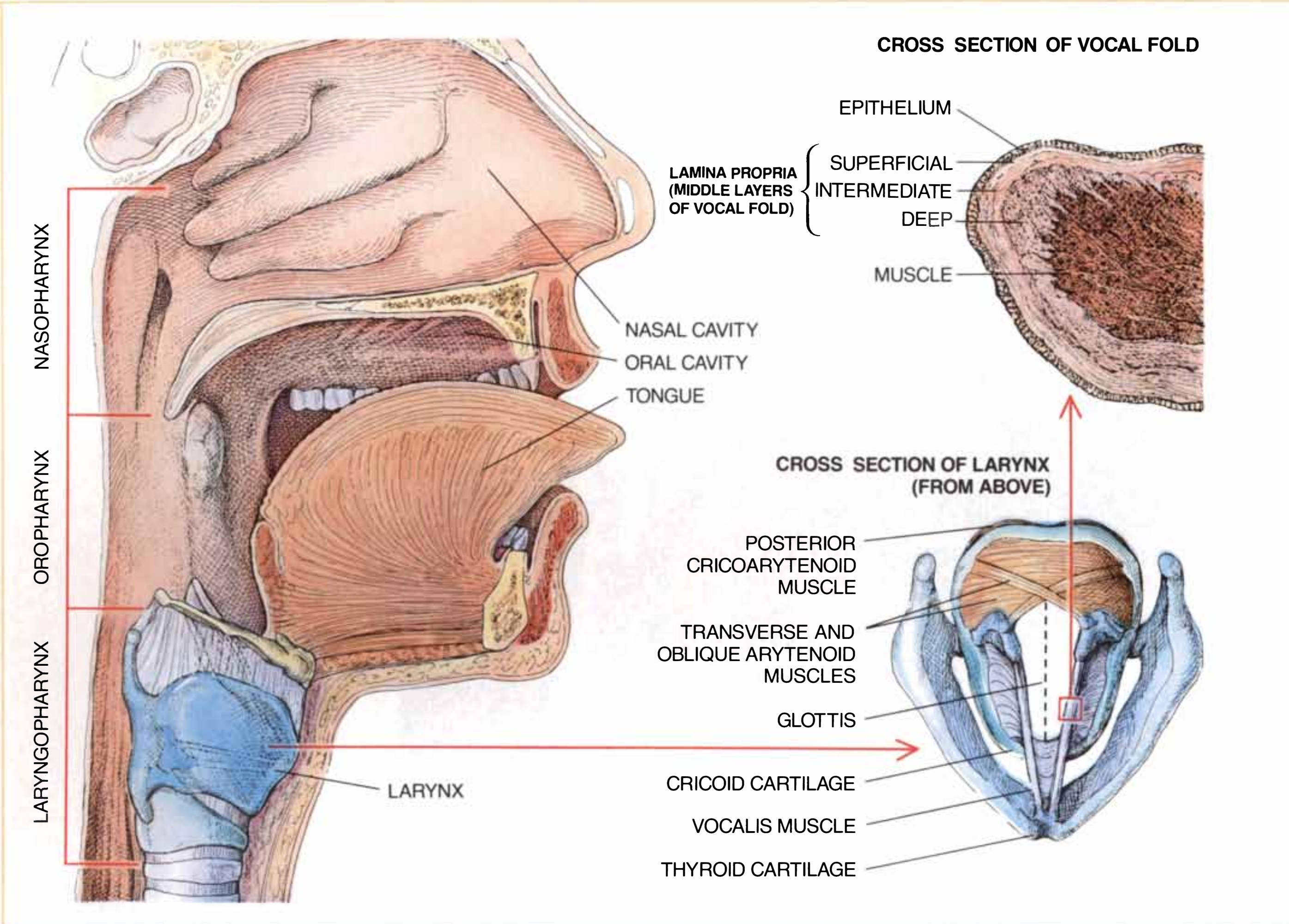
VOCAL-FOLD SURGERY prolonged the career of the popular singer Elton John. He had trouble with his voice during a tour of the U.S. in 1986. The problem turned out to be a nonmalignant lesion, which surgeons successfully removed early in 1987. A year later he was able to resume giving concerts.



structure. Beneath the thin, lubricated epithelium on the surface lie the superficial, intermediate and deep layers of tissue called the lamina propria. Underlying the lamina propria is the thyroarytenoid (or vocalis) muscle itself. The five layers have different mechanical properties that produce the smooth shearing motions essential to healthy vocal-fold vibrations.

When the vocal folds vibrate, they produce only a buzzing sound. That sound resonates, however, throughout the supraglottic vocal tract, which includes the pharynx, the tongue, the palate, the oral cavity and the nose. That added resonance produces much of the perceived character and timbre, or vocal quality, of all sounds in speech and song.

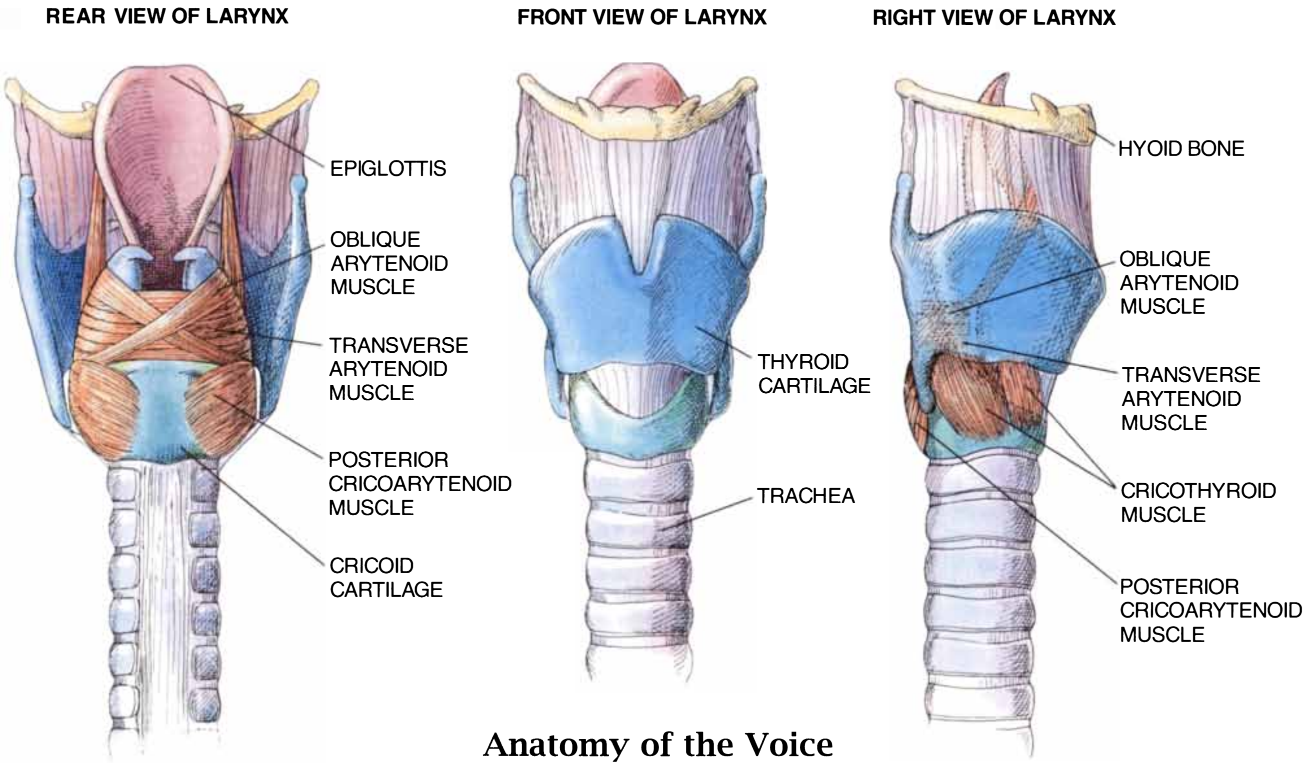
The power source for the voice is the infraglottic vocal tract—the lungs, rib cage and abdominal, back and chest muscles that generate and direct a controlled airstream between the vocal folds. As the glottis closes, opens and alters shape, its air resistance changes almost continuously. The power source must therefore make rapid, complex adjustments to maintain a steady vocal quality. Singers and actors refer generally to the entire power complex as their "support" or "diaphragm." Actually, the anatomy of the power complex is complicated and not completely understood, and performers who use such terms do not always mean the same thing.

The principal muscles of inspiration, or inhalation, are the diaphragm (a dome-shaped muscle that extends along the bottom of the rib cage) and the external intercostal (rib) muscles. Expiration, or exhalation, is largely passive during quiet respiration: the mechanical properties of the lungs and rib cage typically force air out of the lungs effortlessly after a full breath. Of course, active expiration is also possible, and many of the muscles involved in this process are also used to support voice production, or phonation.

During active expiration, muscles may raise the pressure within the abdomen and thereby force the diaphragm upward. Alternatively, they may lower the ribs and sternum to decrease the dimensions of the thorax. The primary muscles of expiration are the abdominal muscles, but internal intercostals and other chest and back muscles also contribute.

Trauma or surgery that alters the structure or function of these muscles undermines the power source of the voice, as do asthma and other diseases that impair expiration. People often compensate for deficiencies in their support mechanism by overworking their laryngeal muscles, which are not designed to serve as a vocal power source. Such behavior can result in decreased function, rapid fatigue, pain and even structural problems, such as vocal-fold nodules.

Like the muscular and skeletal systems, the nervous system also contributes to voice production. The "idea" for a voice sound originates in the cerebral cortex and travels to motor nuclei in the brain stem and spinal cord. These areas send out complicated messages for coordinating the activities of the larynx, the thoracic and abdominal musculature and the vocal-tract articulators. Signals from certain divisions in the nervous system, called the extrapyramidal



Anatomy of the Voice

Vocal mechanism encompasses many muscles and organs of the abdomen, chest, throat and head. The drawing at the far left portrays those in the throat and head. Details of the larynx, or voice box, are shown to the right of that drawing in an orientation looking down on the structure with the front—the Adam's apple—facing the bottom. The two vocalis muscles constitute the bodies of the vocal folds, which were formerly known as the vocal cords; a cross section of one of them appears above the representation of the larynx. The remaining three drawings (*above*) show the major muscles and cartilages of the larynx from the rear (*left*), the front and the right side.

tract and the autonomic nervous system, also refine these activities.

The nerves that control the muscles of the vocal tract are potential sources of voice problems. For example, the two recurrent laryngeal nerves control most of the intrinsic muscles in the larynx. Because those nerves (especially on the left) run through the neck, down into the chest and then back up to the larynx, they are easily injured by trauma or surgery on the neck and chest.

Nerves also provide feedback to the brain about voice production. Auditory feedback, which is transmitted from the ear through the brain stem to the cerebral cortex, allows a vocalist to match the sound produced with the sound intended. Tactile feedback from the throat and muscles also may help with the fine-tuning of vocal output, although that process is not fully understood. Trained singers and speakers cultivate their ability to use tactile feedback effectively because they expect that poor room acoustics, loud musical instruments or crowd noises will interfere with the auditory feedback.

During phonation, all those anatomic structures and systems must work together. The physiology of voice production is exceedingly complex, but the voice can be likened to a trumpet. Power for the sound is generated by the chest, abdomen and back musculature, which produce a high-pressure airstream. A trumpeter's lips open and close against the mouthpiece to create a buzz similar to that produced by the vocal folds. This sound then resonates through the rest of the trumpet, which is analogous to the supraglottic vocal tract.

Much of the progress during the past 20 years has come from filling in the details of how vocal sounds originate and change. Part of this effort has involved modeling the movements of the vocal folds. Although a vocal fold has a five-layer anatomy, it behaves mechanically more like a three-layer structure, consisting of a cover (epithelium and superficial layer of the lamina propria), a transition layer (intermediate and deep layers of the lamina propria) and a body (thyroarytenoid muscle).

Observations and modeling studies have revealed how the larynx produces a sound. Initially, the vocal folds are in contact, and the glottis is closed. As the lungs expel air, pressure below the glottis builds, typically to a level of about seven centimeters of water for conversational speech. This pressure progressively pushes the vocal folds apart from the bottom up, until the glottis is open and air begins to flow. Elastic and other forces resist the separation of the upper margin of the vocal folds, but the airstream overpowers them.

The flow of air, however, produces a Bernoulli effect—that is, a reduction in the lateral air pressure caused by its forward motion. The effect tends to pull the vocal folds shut, as do the elastic properties of the vocal-fold tissues. The pressure of the airstream below the glottis also diminishes as the glottis opens to let the air out.

Because of these factors, the lower edges of the vocal folds begin to close almost immediately, even though the upper edges are still separating. That closure further diminishes the force of the airstream. The upper margins of the vocal folds then snap back to the midline and close the glottis. Subglottal pressure builds again, and the events repeat themselves. (It should be understood that there is direct pressure and that the alternating variations rarely drop the subglottal pressure to zero. This fact is important in understanding the driving forces involved in the motions of the vocal fold.)

An important aspect of this process is that the lower part of the vocal folds begins to open and close before the upper part. The rippling displacement of the vocal-fold cover produces a wave motion in the mucosal layer. If the complex vibration of that glottal wave is impaired, hoarseness or other changes in voice quality may result.

The vocal folds do not excite the air by vibrating like violin strings. Instead, by opening and closing the glottis, they create puffs of air in the vocal tract. The sudden cessation of airflow at the end of each puff produces an acoustic vibration. The mechanism is similar to that which causes the sound of hand clapping.

The sound from the larynx is a complex tone containing a fundamental frequency, or pitch, and many overtones, or higher harmonic partials. (Frequency is measured in hertz, the number of opening and closing cycles in the glottis each second.) Surprising as it may seem, trained and untrained vocalists produce about the same spectrums at the vocal-fold level.

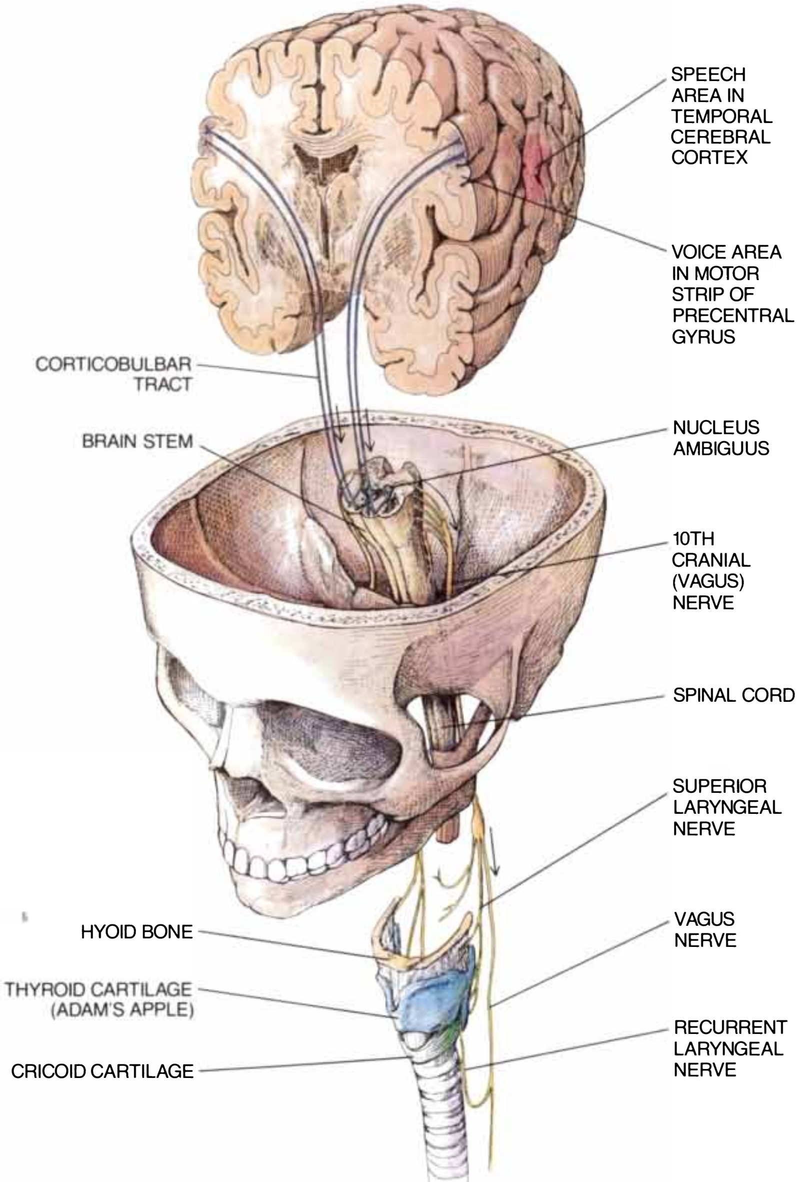
The pharynx (the throat area between the mouth and the esophagus), the oral cavity and the nasal cavity act as a series of interconnected resonators for the voice signal. The system is more complex than a trumpet because its walls, and hence its shape, are flexible. In any resonator, some frequencies are attenuated while others are enhanced, or radiated with higher amplitudes. Certain harmonic partials therefore become relatively softer while others grow louder. Johan Sundberg of the Royal Institute of Technology in Stockholm has shown for singers (and his colleague Gunnar Fant for speakers) that the vocal tract has four or five important resonance frequencies called formants. The intensity of the voice source diminishes uniformly across its frequency spectrum except at the formant frequencies, where it peaks.

Formant frequencies are established by the shape of the vocal tract, which can be altered by the laryngeal, pharyngeal and oral cavity musculature. Overall, the length and shape of one's vocal tract are individually fixed and determined by age and sex: women and children have shorter vocal tracts than do men and consequently have higher formant frequencies. Nevertheless, the dimensions of the vocal tract can be consciously adjusted to some degree, and mastering those adjustments is fundamental to voice training.

One resonant frequency that has received attention is known as the singer's formant. It appears to be responsible for the "ring" in a singer's or speaker's voice. The ability to make oneself heard clearly even over an orchestra depends primarily on the presence of the singer's formant: there is little or no

How the Voice Is Produced

The production of speech or song, or even just a vocal sound, entails a complex orchestration of mental and physical actions. The idea for making a sound originates in the cerebral cortex of the brain—for example, in the speech area. The movement of the larynx is controlled from the voice area and is transmitted to the larynx by various nerves. As a result, the vocal folds vibrate, generating a buzzing sound. It is the resonation of that sound throughout the area of the vocal tract above the glottis—an area that includes the pharynx, tongue, palate, oral cavity and nose—that gives the sound the qualities perceived by a listener. Auditory feedback and tactile feedback enable the speaker or singer to achieve fine-tuning of the vocal output.



significant difference in the maximum vocal intensities of trained and untrained singers.

The singer's formant occurs at around 2,300 to 3,200 hertz for all vowel sounds. Aside from adding clarity and projection to a voice, it also contributes to differences in timbre. The singer's formant occurs in basses at about 2,400 hertz, in baritones at 2,600 hertz, in tenors at 2,800 hertz, in mezzo-sopranos at 2,900 hertz and in high sopranos at 3,200 hertz. The singer's formant is often much less pronounced in sopranos.

Control over two vocal characteristics—fundamental frequency and intensity—is crucial. One way to raise the fundamental frequency is to raise the pressure of the airstream moving through the larynx. For mechanical reasons, as the pressure rises, the vocal folds tend to blow apart and to snap shut more quickly and frequently. Singers learn to compensate for this tendency: otherwise, their pitch would rise whenever they tried to sing louder.

Generally, the most efficient technique for altering the pitch is to change the mechanical properties of the vocal folds. Contracting the cricothyroid muscle makes the thyroid and cricoid cartilages pivot and stretches the vocal folds. This change exposes more surface area on the vocal folds to the airstream and thereby makes them more responsive to air pressure. It also stretches the elastic fibers of the vocal folds and increases their efficiency at snapping back together. The pitch rises because the cycles of opening and closing in the glottis (phonatory cycles) shorten and repeat more frequently.

Vocal intensity, or loudness, depends on how much the vocal-fold vibrations excite the air in the vocal tract. Raising the air pressure increases the amplitude of the vibrations because the vocal folds move farther apart and snap together more briskly. Consequently, during each phonatory cycle, the flow of air through the larynx cuts off more sharply, and the intensity of the produced sound increases. A similar effect increases the intensity of the sound of hand clapping.

A useful biophysical indicator of the efficiency of vocal control strategies can be seen in flow patterns during each phonatory cycle. For example, a vocalist may attempt to increase vocal intensity by excessively raising both the air pressure and the resistance of the glottis to the flow of air, using the muscles of the infraglottic vocal tract and the adductory (glottis-closing) forces of the vocal folds. Such a combination of forces results in a condition called pressed phonation, in which the amplitude of the voice's fundamental frequency is low despite considerable physical effort.

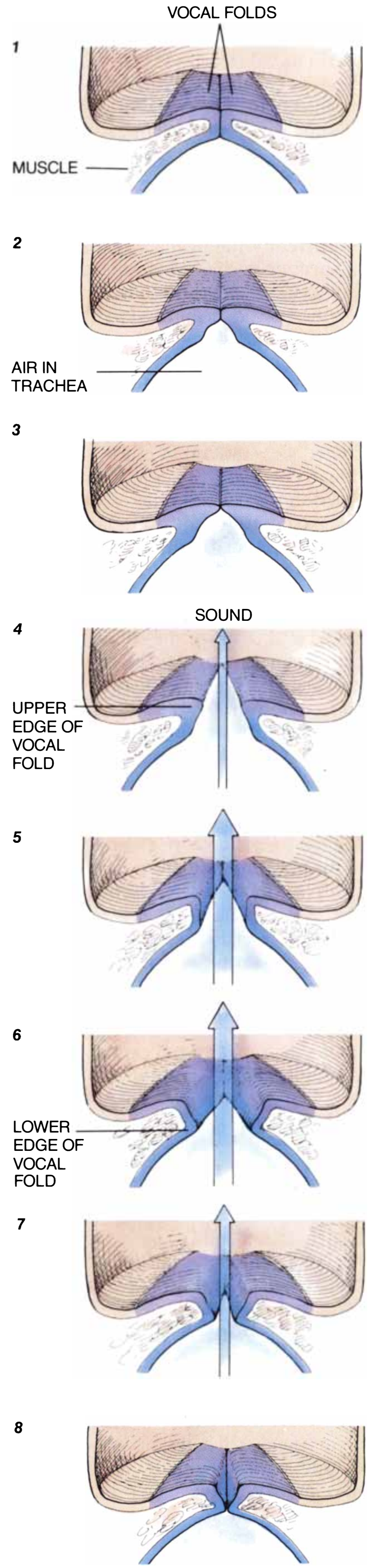
The amplitude of the voice source will also be low if the adductory forces are so weak that the vocal folds do not make contact and the glottis becomes inefficient. This condition results in breathy phonation. In contrast, a third and more desirable condition known as flow phonation is characterized by low airstream pressure and low adductory force, which increase the intensity of the fundamental frequency and make the voice louder. To identify pressed, breathy or flow phonation, voice specialists can plot changes in the flow of air through the glottis, thus producing a graph called a flow glottogram.

Sundberg has shown that a vocalist can raise the amplitude of the fundamental frequency by 15 decibels or more simply by changing from pressed phonation to flow phonation. Hence, people who rely habitually on pressed phonation expend unnecessary effort to achieve a loud voice. The forces and patterns of muscle use recruited to compensate for this inefficiency may damage the larynx.

By understanding the vocal control mechanisms, physicians can detect and correct the problems that abuse the voice and traumatize the vocal folds. Understanding the function of each component of the vocal tract also aids the development of optimal strategies for rehabilitating damaged voices.

The development of new tools has been critical for the science of the voice. Until the 1980s, the physician's ear was routinely the sole instrument used to assess voice quality and function. Practical techniques for observing and quantifying voice functions were generally lacking.

In 1854, for instance, a singing teacher named Manuel García devised the technique of indirect laryngoscopy. He used the sun as a light source and a dental mirror placed in a student's mouth to look at the vocal folds. Indirect laryngoscopy rapidly became a basic tool for physicians, and it is still in



VIBRATION OF VOCAL FOLDS is shown, in a vertical cross section through the middle part of the vocal folds, during the production of a single sound. The perspective is from the front of the larynx. Before the process starts (*1*), the folds are together. They separate as air is forced upward through the trachea (*2–7*) and then come together again as the sound ceases (*8*).

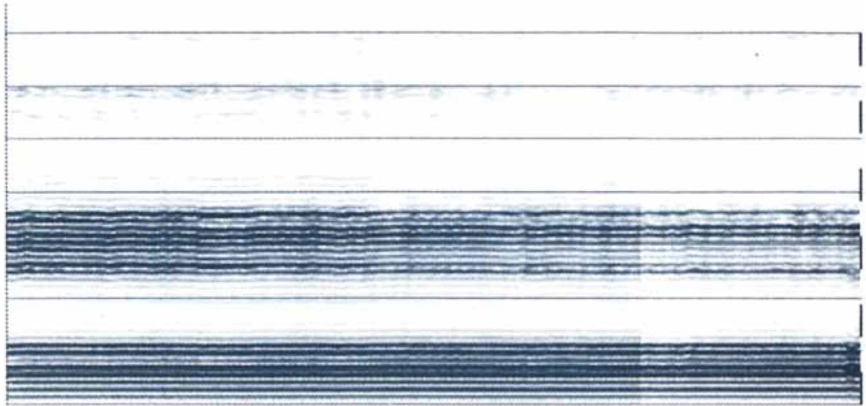
daily use. (Today, of course, we use an electric light instead of the sun.)

Yet as valuable as this technique has been, it has many disadvantages. Effective magnification of the vocal folds and photographic documentation of their condition are difficult. Also, standard lighting does not permit physicians to see the rapid, complex vibrations of the vocal folds.

Currently the primary technique for inspecting vocal-fold vibrations is strobovideolaryngoscopy. It uses a microphone placed near the larynx to trigger a stroboscope that illuminates the vocal folds. If the frequency of the stroboscopic light is about two hertz out of phase with the vibration, an observer can watch the vocal folds in simulated slow motion. A crude version of this technique was actually first developed in the 19th century. Only during the past decade, however, have stroboscopes become bright enough and video cameras sufficiently sensitive for it to be useful routinely.

The stroboscopic effect permits detailed evaluation of the vocal-fold edge. Physicians can see small masses, vibratory asymmetries, scars, early carcinomas and other laryngeal abnormalities—many of which are not detectable under normal light. Digital analysis of the images can also supplement visual assessments, although poor image resolution and some other problems have limited the value of the technique so far.

Another method for monitoring vocal-fold vibrations is electroglottography. A weak high-frequency voltage between two electrodes placed on the neck passes through the larynx. Changes in the measured voltage generate a wave on the electroglottograph that illustrates vocal-fold contact. Information about the open glottis can be inferred from photoglottography, which measures light passed from below the vocal folds, or from flow glottography.



HEALTHY AND AILING VOICES are compared in these sonograms made as the speakers produced the sound of "a" as in "father." Time runs from left to right for about two seconds. The horizontal lines mark off frequencies in hertz from zero at the bottom to 7,000 at the top. The sonogram at the left is from a male speaker

Measurements of aerodynamic function, which include comprehensive testing of pulmonary function and laryngeal airflow, are especially valuable. Together they reveal both the function of the vocal power source and the efficiency of the vocal folds for controlling airflow. Measurements of phonatory ability—the ability to produce sounds—are simple and useful for quantifying vocal dysfunctions and evaluating the results of treatment. Such tests determine the frequency and intensity ranges of the voice, how long a sound can be produced and other factors.

Laryngeal electromyography, another technique for studying voice function, involves the insertion of thin electrodes into the laryngeal muscles. It is useful in specialized circumstances for assessing neuromuscular integrity and function. For instance, measurements of electrical activity in the laryngeal muscles may foretell a patient's recovery from vocal-fold paralysis. In that case, before considering surgery, a physician might recommend waiting for a spontaneous recovery.

A skilled laryngologist or another trained listener can glean much from the sound of a voice. Nevertheless, clinicians and researchers need equipment capable of quantifying the vocal characteristics that are meaningful to the ear. The available equipment is helpful, but it needs further improvement.

For example, acoustic spectrography displays the frequency and harmonic spectrum of a voice and visually records noise. The equipment depicts the acoustic signal and enables researchers or physicians to make generalizations about the vocal quality, pitch and loudness. A variety of qualities can be measured: the formant structure and strength of the voice, the fundamental frequency, breathiness, the harmonics-to-noise ratio (or clarity of the voice) and perturbations of the cycle-to-cycle amplitude ("shimmer") and of the cycle-to-cycle frequency ("jitter"). Subtle characteristics, however, still cannot be detected. For instance, in studies of voice fatigue in trained singers, the difference between a rested and tired voice is usually obvious to the ear, but significant changes cannot be detected consistently even with sophisticated equipment.

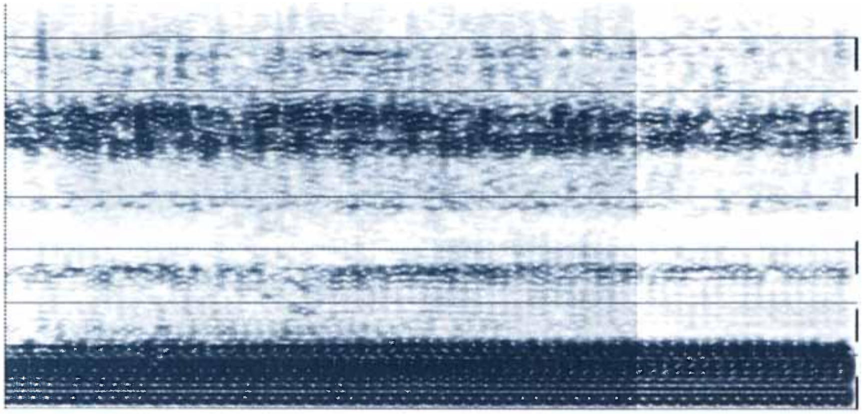
Psychological influences on the voice are also critical, but the techniques for evaluating them are poorly standardized. Nevertheless, well-developed questionnaires, tape recordings and assessment of voice by several observers have boosted the utility of such examinations. All these tools help physicians to detect and record the information contained in the sound of the voice more reliably and validly.

As technology has enhanced the diagnostic and therapeutic aspects of voice medicine, the need for laryngeal surgery has diminished. Some conditions require little more than the prescription of drugs. Medications must be used with caution, however, because even many over-the-counter remedies have side effects that adversely affect voice function. Antihistamines, for example, cause dryness in the vocal mucosa, which can lead to hoarseness and coughing. The anticoagulant properties of aspirin can contribute to vocal-fold hemorrhages.

Techniques have been developed to rehabilitate voices that have been damaged through misuse. Voice therapy facilitates breathing and abdominal support and helps to eliminate unnecessary muscle strain in the larynx and neck. It can even cure some structural problems of the vocal folds, most notably nodules (hard, callouslike growths). Therapy helps patients to learn how to use each component of the vocal tract appropriately so as to avoid straining and abusing their voices, how to maintain the correct levels of moisture and mucus in their vocal tracts and how to mitigate the effects of smoke and other hazards in the environment.

Good vocal hygiene and technique, however, are not always enough. Some structural problems in the larynx must be treated with surgery. These problems include nodules that have not responded to voice therapy, polyps (soft-tissue growths), cysts (fluid-filled masses) and other growths.

Most benign pathological conditions



with normal vocal folds; the one at the right is from a male speaker with growths on his vocal folds. His voice makes additional noise in the range above 5,000 hertz and has disrupted and weakened harmonics between 2,000 and 4,000 hertz. The result is that his voice sounds harsh and hoarse.

are conveniently superficial. By a variety of delicate microsurgical techniques, surgeons can now usually remove lesions from the epithelium or the superficial layer of the lamina propria without disrupting the intermediate or deep layers of the tissue, which form scars. Such procedures are now commonly described as phonosurgery. (That term originally referred only to operations designed to alter vocal pitch and quality.)

Most voice surgery is performed through the mouth while the surgeon views the larynx through a metal tube called a rigid laryngoscope. An operating microscope magnifies the larynx. A surgeon can then treat the laryngeal abnormalities with microscopic scissors, lasers and other instruments.

Nodules, polyps and cysts on the vibratory margin of the vocal folds are removed most safely with traditional surgical instruments. The operations can be remarkably precise: in some cases, it is possible to raise the vocal-fold mucosa, remove a cyst or other underlying mass and then replace the mucosa. Such minimally traumatic surgery does not even require postoperative voice rest, and rapid healing with good voice quality usually follows.

Lasers are often celebrated as revolutionary high-tech surgical instruments, but they are not always the best choice for laryngeal surgery. At the power densities required for the surgical ablation of tissue, the beam from a standard carbon dioxide laser would be surrounded by a heat halo as much as 0.5 millimeter wide. If the beam were directed against a lesion on the edge of the vocal fold, the heat might provoke scarring in the intermediate or deep layers of the lamina propria. Such a scar would create a nonvibrating segment on the vocal fold; hoarseness would result.

Nevertheless, the carbon dioxide laser is extremely useful for some lesions. It can seal off varicose blood vessels in the vocal folds that might hemorrhage, and it can vaporize blood vessels that nourish laryngeal polyps, papillomas and some cancers. Further research and development in laser technology is likely to provide an instrument better suited for microsurgery on the vocal fold in the near future.

New surgical techniques for modifying the laryngeal skeleton have been pioneered by physician Nabuhiko Issiki of Kyoto. These have become extremely useful for treating vocal-fold paralysis, which is a common consequence of viral infections, surgery or cancer. Traditionally, surgeons have treated vocal-fold paralysis by injecting small volumes of Teflon into the affected vocal fold. The Teflon pushes the paralyzed fold toward the midline of the glottis and allows the normal fold to meet it. The glottis can then close, and the patient's voice is often improved.

Yet although Teflon is relatively inert, tissue reactions to it are not uncommon. The stiffness that the Teflon produces in the vocal-fold edge frequently impairs the quality of the voice. Also, if the results of the Teflon injection are unsatisfactory, it is difficult to remove the material from the tissues.

For these reasons, Teflon injections have generally been replaced by thyroplasty. In this technique, a surgeon cuts a small window in the laryngeal skeleton and pushes the thyroid cartilage and the laryngeal tissues inward. The depressed cartilage is then held in place with an inserted Silastic block. Such an operation pushes the vocal fold toward the midline without injecting a foreign body into the tissues, and it appears to be more reversible than Teflon injection. My colleagues and I have also recently introduced an injection technique that uses, instead of Teflon, a small amount of fat harvested from the patient's abdomen or arm. Like the Teflon procedure, this one is relatively simple, and it lacks the disadvantages of Teflon. It requires further study.

Surgery on the laryngeal skeleton can also modify a patient's pitch. A surgeon can raise the pitch by pivoting the thyroid and cricoid cartilages and closing the space between them. These changes lengthen and tense the vocal folds. Alternatively, a surgeon can cut vertical sections out of the thyroid cartilage to shorten the vocal folds, decrease their tension and thereby lower the pitch. The results of such surgery are not sufficiently predictable for singers and other professional voice users to elect them for purely aesthetic reasons. Nevertheless, they are valuable for treating certain voice abnormalities and for adjusting the vocal pitch of patients who have undergone sex-change surgery.

Because most of the gains in treating the human voice have involved collaborations among physicians, voice scientists, speech-language pathologists, teachers and singers, they have found their way into practical use in medical offices unusually quickly. Moreover, educating patients, singing and acting students, voice teachers and the general public about the importance of the voice and its maladies has had gratifying results. Education is often the best preventive medicine, and it has already decreased the prevalence of avoidable voice problems.

For medical progress to continue, we will need even more basic understanding of voice science, better clinical evaluation and quantification tools, and better surgical instruments, such as more effective surgical lasers. We can anticipate not only further clinical advances but also exciting applications in voice training and development.

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