Clark A. Rosen, C. Blake Simpson

Operative Techniques in Laryngology

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C. Blake Simpson

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Forewords by Hans von Leden
and Robert H. Ossoff

With 390 Figures and 11 Tables

Springer

Clark A. Rosen, M.D.
University of Pittsburgh Voice Center
UPMC Mercy Hospital
1400 Locust Street, 2100 Bldg D
Pittsburgh, PA 15219, USA
E-mail: rosenca@upmc.edu

C. Blake Simpson, M.D.
The University of Texas Health Science Center
Department of Otolaryngology
7703 Floyd Curl Drive MC-7777
San Antonio, TX 78229-390, USA
E-mail: simpsonc@uthscsa.edu

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Dedication

I have had the incredible good fortune to be blessed with supportive family, teachers, and friends. It is imperative that I recognize the huge impact of some of these individuals on my personal and professional development and growth. I would like to dedicate this book to my parents, Paul Jack Rosen, M.D., and Shirley Maureen Orr Rosen, who worked tirelessly to provide the optimal growth environment for me and instill in me the best possible work ethic.

Over my many years of education, I have had many wonderful teachers. However, one has had the greatest impact, not only on my knowledge base, but also on my approach to learning, teaching, and academic life. I would like to thank Jamie Cohen, M.D., Ph.D., for being an outstanding role model, mentor, and friend. Eugene N. Myers, M.D. has been vital to me from a professional and career development perspective, for providing me the opportunity to achieve my dreams and goals. Without his support, this book would not have been possible. I would like to acknowledge the primal role of Blake Simpson, M.D., in the development of this book from concept to completion. I have grown as a laryngologist due to our "mind meld" of laryngologic experience and philosophy while writing this book together.

I am indebted to the wonderful group of teachers and colleagues with whom I have had the pleasure and privilege to work: Gayle Woodson, M.D.; Thomas Murry, Ph.D.; Robert Buckmire, M.D.; Lori Lombard, Ph.D.; and Jackie Gartner-Schmidt, Ph.D. I would like to acknowledge the importance of my Fellows and OR staff, without whom many of the concepts in this book would not exist: AT, TK, PK, MJB, AF, TC, SR, SO, NS, CP, MB, Icarus, and MLL.

Lastly and most importantly, I dedicate this book to Monica Anne Linde, without whose support, energy and love, none of my professional success would have been possible.

Sincerely and with deepest gratitude,

Clark A. Rosen M.D.
Pittsburgh, Pennsylvania
March 2008

Dedication

This work is dedicated to my wife, Cristina, and my twin daughters, Juliana and Audrey. I am eternally grateful for all the love and support you have given me.

C. Blake Simpson, M.D.
San Antonio, Texas
March 2008

Foreword

In this age of communication, the care of the human voice and the vocal organ has assumed greater and greater importance. The maintenance of good vocal health and the treatment of the diseased larynx are essential for all members of society—from heads of state to the receptionist with the golden voice on the telephone. The necessity for the restoration of pathologic changes in the larynx has resulted in the application of numerous operative techniques, which may bewilder the clinician. There is a real need for a comprehensive educational resource like *Operative Techniques in Laryngology*.

The two authors of this textbook, Clark A. Rosen and C. Blake Simpson, both leading scholars and experienced surgeons at major medical centers, have created a superb treatise, which expertly details the surgical care of different laryngeal pathologies. The introductory chapters call attention to the current methods of *clinical* evaluation for laryngeal disorders, including videostroboscopy and flexible laryngoscopy, as well as the *medical* treatment of patients with vocal problems. The indicated preoperative measures are discussed in detail, and the importance of anesthesia and airway management during surgical procedures within the larynx are stressed.

Subsequent chapters advance the reader from the fundamental principals of laryngeal surgery to such major surgical techniques as phonomicrosurgery, laser surgery, vocal fold augmentation, and surgery of the laryngeal framework. In successive chapters, each pathologic entity is presented in detail, including the etiology, history, vocal quality, physical examination, surgical intervention, postoperative care, and potential complications. Specific microsurgical procedures are recommended for all common benign lesions and for localized neoplasms of the vocal folds. The use of lasers is described for stenosis of the vocal folds and circumscribed malignant lesions.

The chapters on vocal fold augmentation include precise information on injection techniques via microlaryngoscopy, as well as peroral and percutaneous approaches. Specific chapters are devoted to the principles of operative care for laryngeal framework surgery. These procedures range medialization laryngoplasty or arytenoid adduction to problems more complex such as cricothyroid subluxation, laryngeal fractures, sulcus vocalis, and stenosis of the larynx and trachea.

The reader will be impressed with the clarity of the presentations, which is enhanced by the use of systematic headings, and by the precision and the rich color of the illustrations within each chapter. An abundance of carefully selected references enables the prospective surgeon to pursue further detailed information from various experts as desired. It is apparent that the authors and the publisher have combined their expertise to present an outstanding educational and inspirational textbook for both the clinical otorhinolaryngologist as well as the experienced laryngeal surgeon. I shall cherish my own copy of this exciting edition.

Hans von Leden, M.D., Sc.D.
Professor Emeritus
University of Southern California
Los Angeles, California
February 2008

Foreword

The subspecialty of laryngology has gone through a tremendous period of growth and maturation during the past 20 years. Fellowships dedicated to advanced training in laryngology, neurolaryngology, and voice care are now available at several academic health centers and private practices. Furthermore, it is now very common to find at least one fellowship-trained laryngologist on the full-time faculty of many of our resident education programs in otolaryngology–head and neck surgery in the United States and Canada. The quality of resident education, patient care, and laryngology-related research has improved because of the advances in this subspecialty promoted by this growing critical mass of individuals who have completed fellowships in laryngology and voice care after their formal residency training in otolaryngology. Now, the cycle has come full circle, with several of the earlier fellowship-trained laryngologists directing laryngology fellowship training programs of their own.

Drs. Blake Simpson and Clark Rosen are excellent examples of this training model. Blake spent a year at Vanderbilt in fellowship with me and my colleagues, and Clark spent a year of fellowship training at the University of Tennessee with Dr. Gayle Woodson. Now, both Blake and Clark direct fellowship training programs at their respective institutions.

Operative Techniques in Laryngology fills a real void in the field of laryngology and voice care. Drs. Simpson and Rosen present us with a surgical atlas dedicated to and highlighting modern techniques for microlaryngeal surgery and laryngeal framework surgery. They have selected an outstanding group of experts in the field to whose contributions include not only the step-by-step surgical approach to the many problems covered in the atlas, but also addressing the important medical information associated with the various conditions requiring the surgical procedures highlighted in this book. The quality of the illustrations are excellent, and the reader will feel very confident using this atlas as a primary reference for managing appropriate cases in the operating theatre.

This atlas represents a major contribution to our laryngology literature, and it should find its way to the office of all laryngologists, laryngology fellows, resident education program libraries, and many community-based otolaryngologist–head and neck surgeons who perform a moderated volume of laryngeal surgery in their practices.

I am very proud of Blake and Clark for realizing the vision of the growing need for an atlas of surgical techniques in laryngology. I am honored to have had the opportunity to serve as Blake's fellowship mentor and to have had Clark spend a visiting fellow week at Vanderbilt during his fellowship year with Dr. Woodson. I am further honored to be asked by Blake and Clark to write this foreword to their excellent and very important book.

Robert H. Ossoff, D.M.D., M.D.
Guy M. Maness Professor and Chairman
Department of Otolaryngology
Vanderbilt University Medical Center
Nashville, Tennessee
March 2008

Preface

The field of laryngeal surgery for voice and airway pathologic conditions has dramatically changed over the last 20 years, and the impetus for this book was to reflect these major paradigm shifts, and bring together in one place essential information on the rapidly growing and changing field of laryngeal surgery. The book was written to provide the laryngeal surgeon with: (1) essential background information in voice disorders, (2) step-by-step surgical information for laryngeal surgery, and (3) key pearls and pitfalls about indications, surgical steps, and postoperative management of laryngeal surgeries.

The book provides essential "background" information of which any laryngeal surgeon must have mastery. We feel strongly that a true surgeon is a physician first, and must always approach each patient in a holistic manner, and thus understand the essential anatomy and pathology of voice disorders, as well as the nonsurgical treatment modalities. This supports the concept of vocal medicine, not just vocal surgery.

Once surgery has been chosen as a treatment modality, the surgeon must carefully consider timing, planning, anesthesia, and airway considerations. These important issues are reviewed in Chaps. 8 and 9.

The book encompasses a wide range of laryngeal procedures, and it has been organized around the broad categories of phonomicrosurgery and laryngeal framework surgery. Within phonomicrosurgery, detailed information is provided regarding surgery for benign and malignant vocal fold lesions, vocal fold augmentation, and laser laryngeal surgery. The laryngeal framework surgery sections include essential chapters on "open" treatment for unilateral vocal fold paralysis, bilateral vocal fold paralysis, laryngeal trauma, airway stenosis (glottic, subglottic and tracheal), and vocal fold scar/sulcus vocalis.

All the chapters have been designed to allow the reader to understand indications, contraindications, equipment required, step-by-step aspects of the procedure, perioperative care, and management of complications. In almost every chapter, one will find important insights or pearls that, until now, have only been taught verbally by mentor to student.

We feel that this book will become essential reading for all students of laryngology, and general otolaryngologists performing laryngeal surgery.

We have written each chapter of this book; however, for selected chapters, we have been honored to have leaders in our field with whom we collaborated. We would like to thank all of these truly gifted surgeons for sharing their knowledge and expertise.

This surgical atlas is richly illustrated with detailed, colorful artwork as well as essential photographic documentation. This book would not have been possible without the hard work and phenomenal talent of the medical illustration team at the University of Texas Health Science Center, San Antonio. We would like to personally thank these gifted and insightful individuals: David Baker, David Aten, and Chris McKee.

In closing, we feel that this book brings together a wide variety of new and exciting surgical procedures involving the larynx and upper airway. We would like to thank our supporting staff of Diane Keane and Veronica Aleman, as well as Springer for valuable support from their staff, including Marion M. Philipp and Irmela Bohn.

Clark A. Rosen, M.D.
C. Blake Simpson, M.D.

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Each one of these individuals contributed a portion of the chapter's contents or supplied the initial draft prior to editing.

The authors would like to thank the superb team of medical illustrators at the University of Texas Health Science Center, San Antonio:

David Baker
David Aten
Chris McKee

These individuals worked closely with the authors over a four-year period during the writing of this book. The illustrators went the extra mile, studying cadaveric specimens, attending surgical procedures, and reviewing surgical photos from multiple perspectives. Their mastery of laryngeal anatomy and the surgical perspectives of laryngeal surgery are without peer. Their efforts ultimately resulted in, we believe, the highest quality laryngeal surgical illustrations to date.

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Contents

Contributing Authors

Milan Amin, M.D.
Chief, Division of Laryngology
Department of Otolaryngology
New York University School of Medicine
550 First Avenue, NBV 5E5
New York, NY 10016
USA

Chapter 2: Principles of Clinical Evaluation for Voice Disorders
Chapter 45: Subglottis Stenosis: Laryngotracheal Reconstruction with Grafting

Michiel J. Bové, M.D.
Searle Building
Room 12-561
320 Superior
Chicago, IL 60611
USA

Chapter 2: Principles of Clinical Evaluation for Voice Disorders

Mark Courey, M.D.
UCSF Voice & Swallowing Center
2330 Post Street, 5th Floor
San Francisco, CA 94115
USA

Chapter 28: Posterior Glottis Stenosis—Endoscopic Approach (Laser Division with MMC)

Jonathan R. Grant, M.D.
Dept. of Otolaryngology and Communication Sciences
Medical College of Wisconsin
Milwaukee, IL
USA

Chapter 34: Percutaneous VF Augmentation in a Clinical Setting

Patrick J. Gullane, M.D.
7-242 Eaton Wing N
Toronto General
200 Elizabeth Street, Room 3S438
Toronto, Ontario M5G 2CH
Canada

Chapter 46: Glottic and Subglottic Stenosic: Cricotracheal resection with primary anastamosis

Rene Gupta, MD
Department of Otolaryngology
New York University School of Medicine
550 First Avenue, NBV 5E5
New York, NY 10016
USA

Chapter 29: Subglottis Stenosis: Laryngotracheal Reconstruction with Grafting

Michael Johns, M.D.
Emory Health Care
Dept. of Otolaryngology
550 Peachtree Street, Suite 9-4400
Atlanta, GA 30308
USA

Chapter 1: Anatomy and Physiology of the Larynx

Priya Krishna, M.D.
University of Pittsburg
Voice Center
Department of Otolaryngology
200 Lothrop Street, Suite 500
Pittsburgh, PA 15213
USA

Chapter 7: Medical Treatment of Voice Disorders

Albert Merati, M.D.
University of Washington
Department of Otolaryngology
Box 356515
Health Sciences Building
Suite BB1165
Seattle, WA 98195

Chapter 34: Percutaneous VF Augmentation in a Clinical Setting
Chapter 47: Tracheal Resection with Primary Anastomosis

Christine Novak PT
7-242 Eaton Wing N
Toronto General
200 Elizabeth Street, Room 3S438
Toronto, Ontario M5G 2CH
Canada

Chapter 46: Glottic and Subglottic Stenosic: Cricotracheal resection with primary anastamosis

Gregory Postma, M.D.
Department of Otolaryngology
Medical College of Georgia
1120 15th Street
Augusta, GA 30912
USA

Chapter 39: Goretex Medialization Laryngoplasty

Anthony Rider, MD
Department of Otolaryngology and Communication Sciences
Medical College of Wisconsin
Milwaukee, WI
USA

Chapter 47: Tracheal Resection with Primary Anastomosis

Robert T. Sataloff, M.D.
1721 Pine Street
Philadelphia, PA 19103
USA

Chapter 22: Vocal Fold Varix

Lucian Sulica, M.D.
10 Union Square East, Suite 4J
New York, NY 10003
USA

Chapter 35: Botox Toxin Injection
Chapter 37: Peri-Operative Care for Laryngeal Framework Surgery
Chapter 38: Principles of Laryngeal Framework Surgery
Chapter 48: Mini-Thyrotomy for Vocal Fold Scar

Part A Clinical Evaluation of Laryngeal Disorders

Chapter 1

Anatomy and Physiology of the Larynx

1

1.1 Anatomy

1.1.1 Laryngeal Cartilages

1.1.1.1 Thyroid

The laryngeal skeleton consists of several cartilaginous structures (Fig. 1.1), the largest of which is the thyroid cartilage. The thyroid cartilage is composed of two rectangular laminae that are fused anteriorly in the midline. The incomplete fusion of the two laminae superiorly forms the thyroid notch. Attached to each lamina posteriorly are the superior and inferior cornua. The superior cornua articulate with the greater horns of the hyoid bone, while the inferior cornua form a synovial joint with the cricoid cartilage (the cricothyroid joint). At the junction of each superior cornu with its respective thyroid ala is a cartilaginous prominence, the superior tubercle. The superior tubercle is of significance because it marks the point 1 cm below which the superior laryngeal artery and nerve cross over the lamina from laterally to pierce the thyrohyoid membrane. The sternothyroid and the thyrohyoid strap muscles attach to the anterior surface of the thyroid laminae at the oblique line. The inferior pharyngeal constrictor muscles insert on the posterior edge of each thyroid lamina.

The relationship of the internal laryngeal structures to the surface anatomy of the thyroid cartilage is important in surgical planning, particularly in planning the placement of the window for thyroplasty. The level of the vocal fold lies closer to the lower border of the thyroid cartilage lamina than to the upper, and not at its midpoint, as is frequently (and erroneously) stated. Correct placement of the window is necessary to avoid medialization of the false vocal folds or ventricular mucosa.

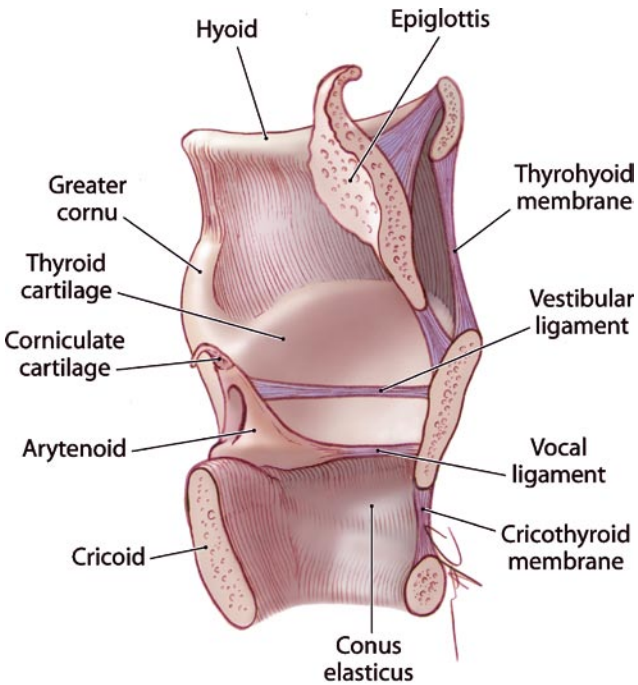

Fig. 1.1 Cartilaginous and fibroelastic structures of the larynx

1.1.1.2 Cricoid

This signet ring-shaped cartilage is the only laryngeal cartilage to encircle completely the airway. The cricoid cartilage articulates with the thyroid cartilage's inferior cornua on the cricothyroid joint facets. It joins the first tracheal ring inferiorly via membranous attachments. The face of the cricoid cartilage has a vertical height of only about 3–4 mm, while the lamina posteriorly stands about 20–30 mm high. There is a steep incline from anterior to posterior of the superior margin of the cricoid cartilage. This incline leaves an anterior window where the cricothyroid membrane lies.

1.1.1.3 Arytenoid

The arytenoid cartilages are paired, pyramidal cartilages that articulate with the posterior lamina of the cricoid cartilage at the cricoarytenoid joint. Each arytenoid has both a vocal process medially and a muscular process laterally. These processes act as the attachment sites for the vocal ligament and the major intrinsic muscles of vocal fold movement respectively.

1.1.1.4 Accessory Cartilages: Cuneiform and Corniculate

The cuneiform cartilages are crico-arytenoid joint paired elastic cartilages that sit on top of, and move with, the corresponding arytenoid. The soft tissue of the aryepiglottic folds covers these cartilages. The corniculates are small, paired, fibroelastic cartilages that sit laterally to each of the arytenoids, and are completely embedded within the aryepiglottic folds. These

1

likely serve to provide additional structural support to the aryepiglottic folds.

1.1.1.5 Epiglottis

The epiglottis is an oblong, feather-shaped fibroelastic cartilage that is attached, at its inferior end, to the inner surface of the thyroid cartilage laminae just above the anterior commissure. The major function of the epiglottis is to help prevent aspiration during swallowing. The epiglottis is displaced posteriorly by tongue base contraction and laryngeal elevation. This causes the superior free edge of the epiglottis to fall over the laryngeal inlet, which, in conjunction with sphincteric closure of the larynx at the glottic and supraglottic level, closes off the laryngeal vestibule.

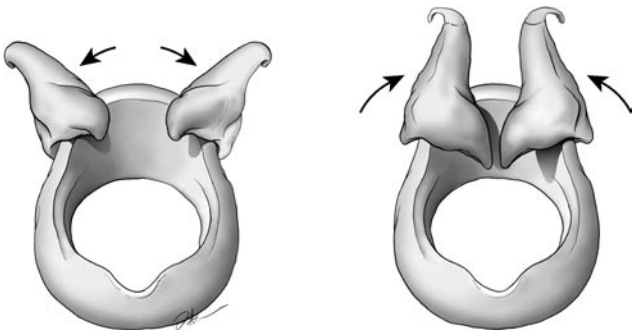

Fig. 1.2 Cricoarytenoid joint action in abduction (*left*) and adduction (*right*). Note the lowering of the vocal process as adduction occurs

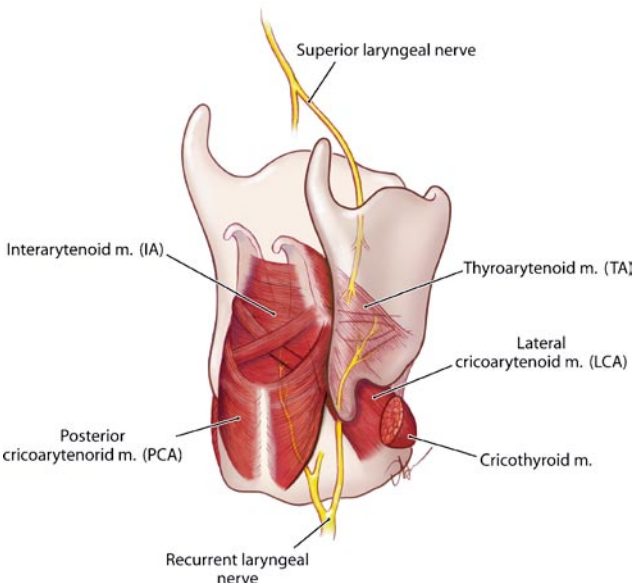

Fig. 1.3 Neuromuscular structures of the larynx

1.1.2 Laryngeal Joints

1.1.2.1 Cricothyroid Joint

The cricothyroid joint is a synovial joint formed from the articulation of the inferior cornua of the thyroid cartilage with facets on the cricoid lamina. The two major actions at this joint are anteroposterior sliding and rotation of the inferior thyroid cornu upon the cricoid cartilage. Cricothyroid muscle contraction pulls the thyroid ala anteriorly with respect to the cricoid cartilage and closes the anterior visor angle between the thyroid and the cricoid cartilage. This motion increases the distance between the anterior commisure and the vocal processes and serves to lengthen and tense the vocal folds. This joint can be manipulated to assist in pitch control in cases of paralytic dysphonia. Cricothyroid joint subluxation, resulting in an exaggerated decrease in the anterior cricothyroid angle, can assist in traditional medialization procedures to provide vocal fold tightening.

1.1.2.2 Cricoarytenoid Joint

The cricoarytenoid joint is the primary moving structure of the intrinsic larynx (Fig. 1.2). The arytenoids articulate with the cricoid cartilage forming multiaxial joints. The action of movement at the cricoarytenoid joints changes the distance between the vocal processes of the two arytenoids and between each vocal process and the anterior commissure. The combined action of the intrinsic laryngeal muscles on the arytenoid cartilages alters the position and shape of the vocal folds. Each cricoarytenoid joint sits at a surprisingly steep 45° angle with the horizontal plane on the cricoid cartilage and permits motion in a sliding, rocking, and twisting fashion.

1.1.3 Laryngeal Musculature

1.1.3.1 Intrinsic Laryngeal Muscles

The intrinsic muscles of the larynx are responsible for altering the length, tension, shape, and spatial position of the vocal folds by changing the orientation of the muscular and vocal processes of the arytenoids with the fixed anterior commissure (Fig. 1.3). Traditionally, the muscles are categorized into the following scheme: three major vocal fold adductors, one abductor, and one tensor muscle.

Adductor Muscles

The Lateral Cricoarytenoid Muscle (LCA)

This paired laryngeal muscle is attached to the anterior part of the muscular process medially and to the superior border of the cricoid cartilage laterally. Contraction of this muscle results in movement of the muscular process anterolaterally,

while simultaneously forcing the vocal process downward and medially. The result is adduction and lengthening of the vocal folds. This muscle runs lateral and in large part parallel with the thyroarytenoid muscle.

Thyroarytenoid Muscle (TA)

The thyroarytenoid muscle consists of two main muscle bellies, the internus and the externus. The thyroarytenoid externus inserts anteriorly at the anterior commissure (Broyles' ligament), and posterolaterally on the lateral surface of the arytenoid. During contraction of this portion of the muscle, the vocal process is brought closer to the anterior commissure and the vocal folds are shortened and adducted. The thyroarytenoid internus arises from the anterior commissure and inserts onto the vocal process of the arytenoid cartilage. During contraction, the vocal folds are shortened and thickened. This portion of the thyroarytenoid is also known as the vocalis muscle. In isolation, this action serves to lower the resonant frequency of the vocal folds. In most cases, there is a significant superior extension of the TA muscle into the false vocal folds, often referred to as the ventricularis muscle.

Interarytenoid Muscle (IA)

This nonpaired muscle consists of both transverse fibers and oblique fibers. The transverse fibers insert on the posterior face of each arytenoid and run horizontally, while the oblique fibers attach to each arytenoid apex and run obliquely to attach to the posterior face on the opposite side. Contraction of this muscle leads to arytenoid adduction, closure of the posterior glottis, and narrowing of the laryngeal inlet. Some oblique fibers extend to travel along the quadrangular membrane and are referred to as the aryepiglottic muscle

Abductor Muscle

Posterior Cricoarytenoid Muscle (PCA)

The posterior cricoarytenoid muscle arises from the posterior face of the cricoid lamina. Its fibers run diagonally to insert on the muscular process of the arytenoid. Contraction displaces the muscular process posteriorly and caudally, while the vocal process moves upward and laterally. The result is vocal fold abduction. The posterior cricoarytenoid is the only abductor of the vocal folds and is principally responsible for control of the glottic airway. The posterior cricoarytenoid muscle affects motion at the cricoarytenoid joint in two planes by its two separate muscle bellies. The medial portion of the posterior cricoarytenoid (horizontal belly) arises from the posterior cricoid lamina and courses obliquely in a superiolateral fashion to insert on the medial aspect of the muscular process. The lateral portion (vertical belly) runs in a more vertical fashion to insert on the lateral side of the muscular process. Because of slightly different positions and orientations, contraction of each muscle belly in isolation causes cricoarytenoid joint motion about a different oblique axis. The horizontal belly has been shown, in cadaver studies, to cause motion in a more vertical axis (true vocal fold abduction), while the vertical belly keeps the arytenoids "upright" and has a major role in vocal fold length and tension. The PCA muscle anatomy serves as a key landmark for arytenoid adduction surgery.

Tensor Muscle

Cricothyroid Muscle

The cricothyroid muscle is a laryngeal tensor, composed of two separate muscle bellies, located on the external surface of the laryngeal cartilages. The pars recta, the more vertical component, arises laterally from the superior rim of the cricoid cartilage and inserts on the inferior rim of the thyroid cartilage, while the pars obliqua, runs obliquely from the superior arch of the cricoid to insert on the inferior cornu. Contraction of the cricothyroid muscle bellies affects motion at the cricothyroid joint. During contraction, the cricothyroid space is narrowed anteriorly, while the posterior cricoid lamina and cricoarytenoid joints are forced caudally, resulting in lengthening, tightening and thinning of the vocal folds and as well as increasing their resonant frequency. This action also results in vocal fold adduction.

1.1.3.2 Extrinsic Laryngeal Muscles

The infrahyoid strap muscles (the sternothyroid, the sternohyoid, and the thyrohyoid), the mylohyoid, digastric, geniohyoid, and stylopharyngeus muscles all act in concert to provide laryngeal stabilization, and indirectly may affect vocal fold position.

1.1.4 Fibroelastic Tissue of the Larynx

1.1.4.1 Quadrangular Membrane

The quadrangular membrane is an accessory elastic support structure of the supraglottic larynx. It attaches anteriorly to the lateral edges of the epiglottis, and wraps around posteriorly to attach to the arytenoids. The superior free edge of the quadrangular membrane is the mucosa-covered aryepiglottic fold. As the quadrangular membrane extends inferiorly, it becomes the medial wall of the piriform sinus. At its inferior extent, it is continuous with the vestibular ligament.

1.1.4.2 Conus Elasticus

The thick fibroelastic support structure of the glottis and subglottis originates inferiorly along the superior border of the cricoid cartilage. Is extends superiorly to attach to the anterior commissure and vocal processes. The conus elasticus rolls medially within the substance of the vocal fold; its medial extent is the vocal ligament. Anteriorly, the conus elasticus is continuous with the cricothyroid membrane.

1.1.5 Microanatomy of the Vocal Fold

The complex microanatomy of the true vocal fold allows the loose and pliable superficial mucosal layers to vibrate freely over the stiffer structural underlayers (Fig. 1.4). The true vocal fold can be divided into three major layers: the mucosa, the vocal ligament, and the underlying muscle. The mucosa of the vocal fold is highly specialized for its vibratory function; it can also be divided into layers. The most superficial layer is the squamous epithelium. Deep to the epithelium are three layers of lamina propria, each of increasing rigidity. The most superficial layer (superficial layer of the lamina propria, or SLP) is mostly acellular and composed of extracellualar matrix proteins, water, and loosely arranged fibers of collagen and elastin. The SLP is gelatinous in nature. The potential space between the SLP and the intermediate layer of lamina propria is Reinke's space. The intermediate and deep layers of the lamina propria (ILP and DLP) are composed mostly of elastin and collagen; the deepest and most dense layer (DLP) is composed of tightly arranged collagen fibers. The ILP and DLP together form the vocal ligament. The gelatinous superficial layer of the lamina propria, together with the squamous epithelium, moves freely over the underlying vocal ligament and muscle to form the vibrations that produce sound.

The vocal fold mucosa and vocal ligament cover the vocalis muscle and extend from the anterior commissure to the vocal processes of the arytenoids. The mucosa and vocal ligament extend posteriorly to cover the entirety of the vocal process. The posterior third of the endoscopically visualized true vocal fold, then, is the aphonatory (respiratory), or cartilaginous portion, while the anterior two thirds of the endoscopically visualized vocal fold is the phonatory, or membranous portion.

1.1.6 Vasculature

The arterial supply to the larynx comes from the superior and inferior laryngeal arteries; the venous supply mirrors the arterial supply. The superior laryngeal artery is a branch of the superior thyroid artery, which arises directly from the external carotid. The superior laryngeal artery branches from the superior thyroid artery at the level of the hyoid bone. This artery then courses medially with the internal branch of the superior laryngeal nerve and enters the thyrohyoid membrane 1 cm anterior and superior to the superior tubercle. The cricothyroid artery, one of the major branches of the superior laryngeal artery, runs along the inferior surface of the thyroid cartilage to supply its similarly named muscle and joint. Branches of this artery pierce the cricothyroid membrane and ascend on the internal surface of the thyroid cartilage, making them possible targets during the creation of a thyroplasty window. The second major arterial supply to the larynx comes from the inferior laryngeal artery, a branch of the inferior thyroid artery. This artery enters the larynx between fibers of the inferior constrictor muscle and anastomoses with branches of the superior laryngeal artery.

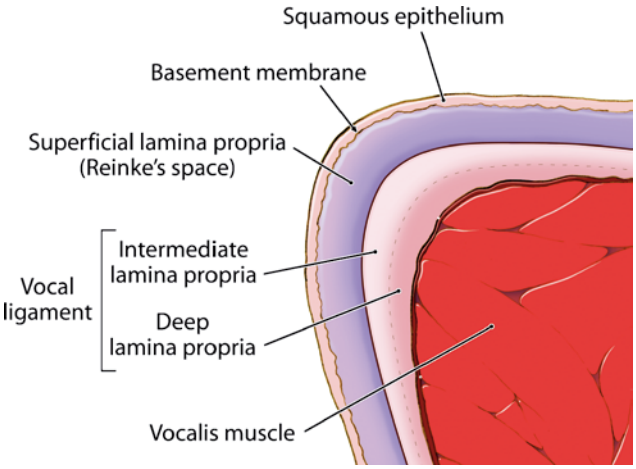

Fig. 1.4 Coronal section through the free edge of the vocal fold, demonstrating the layered microanatomical structures that allow vibration

1.1.7 Innervation

Corticobulbar fibers from the cerebral cortex descend through the internal capsule and synapse on the motor neurons in the nucleus ambiguus. The nucleus ambiguus is the area within the brainstem (medulla) from which the fibers that will contribute to the vagus nerve arise. Lower motor neurons leave the nucleus ambiguus and travel laterally, exiting the medulla between the olive and the pyramid as a series of eight to ten rootlets. These rootlets coalesce into a single nerve root, known as the vagus nerve, which then exits the skull base via the jugular foramen. The vagus nerve descends in the carotid sheath, giving off three major branches: the pharyngeal branch, the superior laryngeal nerve (SLN), and the recurrent laryngeal nerve (RLN). The SLN supplies sensation to the glottic and supraglottic larynx, as well as motor input to the cricothyroid muscle, which controls vocal fold lengthening and pitch. There are some recent anatomic studies that suggest that the superior aspect of the TA muscle (the ventricularis muscle in the false vocal fold) may have SLN innervation, which could explain the presence of false vocal fold muscular contraction in cases of RLN transection. The RLN arises from the vagus nerve in the upper chest and loops under the aortic arch (left) or subclavian artery (right), and ascends back into the neck, traveling in the tracheoesophageal groove. The nerve enters the larynx posteriorly, adjacent to the cricothyroid joint (Fig. 1.3). The RLN innervates the ipsilateral posterior cricoarytenoid (PCA), the interarytenoid (IA) (an unpaired muscle), and the lateral cricoarytenoid (LCA), and terminates in the thyroarytenoid (TA). Thus, the RLN supplies all of the intrinsic laryngeal muscles with the exception of the cricothyroid muscle (and possibly the ventricularis muscle, as indicated above). Ipsilateral RLN transection typically results in vocal fold immobility (the ipsilateral CT does not contribute to vocal fold adduction or abduction). It is important to remember, however, that the interarytenoid muscle is unpaired,

and contralateral RLN input to the IA may lead to some adduction of the vocal fold on the paralyzed side.

The RLN also supplies the glottic and subglottic mucosa and the myotatic receptors of the laryngeal musculature.

1.2 Physiology

1.2.1 Major Laryngeal Functions: Lower Airway Protection, Respiration, and Phonation

The most primitive of the laryngeal functions is protection of the airway. In humans, the larynx has evolved into a highly complex and specialized organ not only for airway protection and control of respiration, but also for sound and speech production. Precise control of all of these mechanisms, as well as exact anatomic structure, is required for normal laryngeal functioning. The larynx has evolved several important reflexes for the purpose of airway protection against external stimuli and foreign bodies. These reflex mechanisms are relayed by the mucosal (sensory afferent), myotatic, and articular receptors of the larynx via both the superior and recurrent laryngeal nerves (Fig. 1.3).

The strongest of the laryngeal reflexes is that of laryngospasm—a response to mechanical stimulation. The larynx has also evolved reflexes that produce cough, apnea, bradycardia, and hypotension.

1.2.1.1 Phonation

The most complex and highly specialized of the laryngeal functions is sound production. The ability to couple phonation with articulation and resonance allows for human speech. Phonation and precisely how it relates to laryngeal vibration has undergone many evolving theories over the years. Sound production requires that several mechanical properties be met. There must be adequate breath support to produce sufficient subglottic pressure. There also must be adequate control of the laryngeal musculature to produce not only glottic closure, but also the proper length and tension of the vocal folds. Finally, there must be favorable pliability and vibratory capacity of the tissues of the vocal folds. Once these conditions are met, sound is generated from vocal fold vibration.

The detailed contribution, timing, and recruitment of each of the above-described laryngeal muscles in the production of sound have been studied. In a fine-wire electromyographic study of human larynges, it was found that the intrinsic laryngeal muscles are not only highly specialized for their particular vector of action, but they are also controlled for the timing of onset of contraction, and the degree of recruitment and fade during phonation. The thyroarytenoid and the lateral cricoarytenoid muscles have been shown to exhibit burst-like activity at the onset of phonation (as well as pre-phonatory), with a measurable degree of fade during sustained phonation. The interarytenoid muscle, on the other hand, has been shown to have increased latency of contraction, but regular sustained tonicity during prolonged sound production. The cricothyroid seems to have the greatest measurable action with increases in pitch and volume, while the posterior cricoarytenoid shows its greatest degree of activation with voluntary deep inhalation and sniff functions.

Actual phonation is a complex and specialized process that involves not only brainstem reflexes and the muscular actions described above, but high-level cortical control as well. Accessory effects such as lung capacity, chest wall compliance, pha-

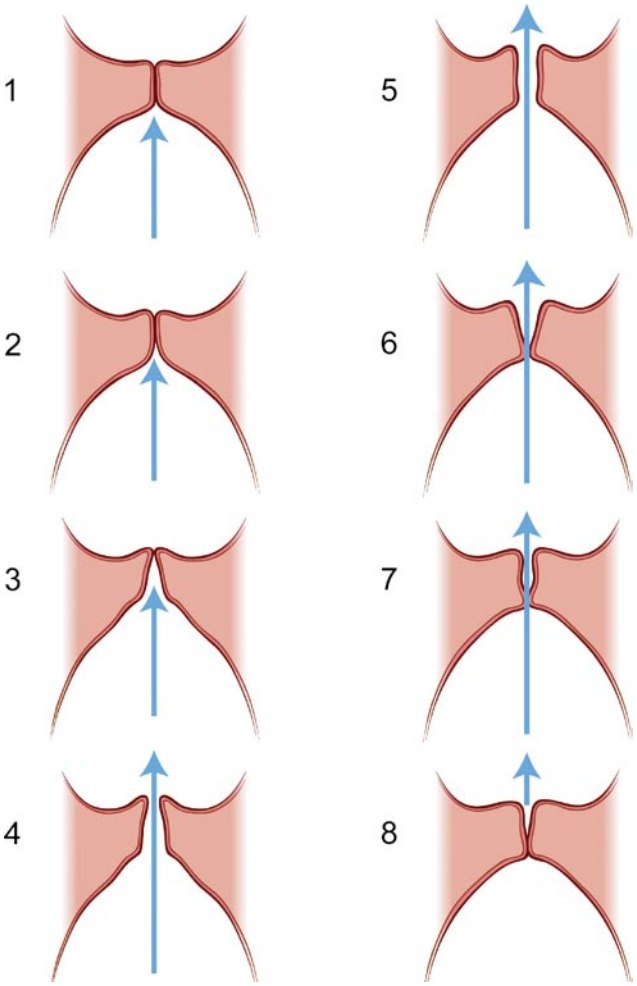

Fig. 1.5 Schematic coronal section through the vocal folds, demonstrating mucosal wave propagation. *1* Vocal folds are completely closed as subglottal pressure (*arrow*) builds up. *2* Lower lips separate due to rising subglottal pressure. *3* Only the upper lips are in contact. *4* A puff of air is released as the vocal folds separate completely. *5*, *6* As airflow continues, the elastic recoil of the vocal folds, as well as Bernoulli's forces, result in the lower lips of the vocal folds drawing inward. At the same time, the mucosal wave is propagated superiolaterally. *7* Airflow is reduced, and the lower lips are completely approximated. *8* In a zipper-like closure, the free edge of the vocal folds come into contact from inferiorly to superiorly

ryngeal, nasal, and oral anatomy, and subsequent mental status also play a role. The process begins with inhalation and subsequent glottal closure. An increase in subglottic pressure follows until the pressure overcomes the glottal closure force and air is allowed to escape between the vocal folds. Once air passes between the vocal folds, the body-cover concept of phonation takes effect. The body-cover theory describes the wave-like motion of the loose mucosa of the vocal folds over the stiffer, more densely organized vocal ligament and vocalis muscle. This motion is known as the mucosal wave. The wave begins infraglottically and is propagated upward to the free edge of the vocal fold and then laterally over the superior surface (Fig. 1.5). Eventually, the inferior edges become reapproximated due both to a drop in pressure at the open glottis, and to the elastic recoil of the tissues themselves. The closure phase is also propagated rostrally. With the vocal folds fully approximated, subglottic pressure may again build and the cycle is repeated (Fig. 1.5).

Key Points

1. The relationship of the surface anatomy of the thyroid and arytenoid cartilages to the internal laryngeal structures are critical to surgical planning for laryngeal framework surgery and in-office procedures (i. e., percutaneous laryngeal injections).
2. The primary adductor muscles of the larynx consist of:
   - Lateral cricoarytenoid (LCA)
   - Thyroarytenoid (TA)
   - Interarytenoid (IA)
3. The main abductor muscle of the larynx is the posterior cricoarytenoid (PCA).
4. The cricothyroid and the TA/LCA muscles control vocal fold length, tension, and vocal frequency.
5. The microanatomy of the vocal folds is complex and consists of the following layers, from superficial to deep:
   - Epithelium
   - Superficial lamina propria
   - Intermediate lamina propria
   - Deep lamina propria
   - Vocalis muscle
6. Reinke's space is a potential space between the superficial and intermediate layer of the lamina propria. The intermediate and deep layers of the lamina propria together are referred to as the vocal ligament.

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Chapter 2

Principles of Clinical Evaluation for Voice Disorders

2

2.1 Fundamental and Related Chapters

Please see Chaps. 1, 3, 4, and 5 for further information.

2.2 Introduction

Many processes resulting in dysphonia affect the vocal folds in subtle ways. Objective evidence of vocal pathology is not always easily discernable on physical examination, even when aided with sophisticated diagnostic instruments. It is, therefore, essential that the laryngologic exam be supported by a careful review of the patient's medical and vocal history. Perhaps more than any other aspect of otolaryngology, the information derived from a careful review of the patient's complaints provides an invaluable context within which to interpret the findings on physical exam and objective voice testing.

2.3 Gathering a Patient History

A detailed and directed questionnaire mailed to patients before their office visits can have multiple advantages. First, it enables patients to record accurately the symptoms they are experiencing and to chronicle the history of their problems. It also allows them to document comprehensively and accurately all their medications and dosages. Addresses and telephone numbers of primary care and referring physicians can also be obtained. This strategy not only increases the efficiency of an office consultation, but it may also allow preliminary differential diagnosis to be formulated in certain patients. To this aim, Sataloff has developed a pair of questionnaires, one directed at the singer, another at the professional voice user. Standardized, patient-based, voice-related quality of life instruments should also be given to the patient prior to the start of the patient evaluation (see Sect. 2.9, "Listening to the Voice").

Although useful, the questionnaire cannot substitute for a thoughtful and thorough face-to-face interview with the patient. The classic template of history of present illness, past medical history, past surgical history, review of systems, medications, and social history provides a reliable framework for achieving a thorough medical and voice history.

2.4 History of Present Illness

The exact nature of the voice patient's chief complaint should be reviewed with care. The term *hoarseness*, for instance, is often used to describe a variety of symptoms, including loss of upper register, roughness, pitch instability, difficulty in transition between singing registers, breathiness, and early vocal fatigue. Each of these symptoms can have distinct implications. A *rough voice* is often associated with abnormalities of the free edge of the vocal fold, as seen in laryngitis or mass lesions. *Breathiness*, on the other hand, results from any condition preventing full approximation of the vocal folds leading to excessive loss of air during vocalization. Conditions that may cause breathiness include vocal fold paralysis/paresis, ankylosis of the cricoarytenoid joint, arytenoid dislocation, vocal fold scar, vocal fold lesions, and presbylarynx. *Raspiness* refers to a disruption of the vocal harmony that usually reflects perturbation of normal mucosal wave, resulting in instability of the fundamental frequency. A strained voice is often the result of hyperfunctional glottal closure. Although primary glottal hyperfunction may be the result of neurological impairment or poor vocal technique, this hyperfunction may also represent a supraglottic compensation for glottal insufficiency. Early vocal fatigue can similarly result from glottal incompetence secondary to vocal fold atrophy, vocal fold scar, vocal fold lesions, or paresis. Inadequate airflow production from the lungs due to pulmonary or neuromuscular pathologies can also present with vocal fatigue and/or decreased volume.

Determining the duration of each voice complaint will distinguish acute processes from chronic dysfunction. An acute process, such as an upper respiratory infection, for instance, may unmask or exacerbate a separate and potentially more consequential chronic process such as a vocal lesion or a pattern of vocal misuse. In addition, upper respiratory infection (URI) symptoms frequently precede the onset of a viral vagal neuropathy. Careful attention to the duration of each of a patient's symptoms will thereby allow a complex symptom picture to be segregated into its component pathologies. The exact time course of the ailment can be particularly helpful in the evaluation of rapid onset dysphonia. Sudden development of hoarseness (occurring over seconds or minutes) should, in fact, always raise suspicion of vocal fold hemorrhage or psychogenic etiologies.

2.5 Past Medical History

Salient points regarding the patient's history include any condition or medications potentially affecting pulmonary status, posture, and hydration. Chronic obstructive pulmonary disease (COPD) will adversely affect the power supply for the patient's voice. Various rheumatological and musculoskeletal ailments can alter posture, impairing voice quality. Any underlying acute or chronic inflammatory conditions can significantly affect voice. Allergic disease manifesting as persistent postnasal drip, for instance, will lead to chronic laryngeal inflammation and vocal fold trauma. Anticholinergic effects of prescription, as well as over the counter medications, can affect mucosal hydration and lubrication, and have an adverse effect on vocal fold vibration.

It has been estimated that approximately half of patients presenting with laryngeal and voice disorders have laryngopharyngeal reflux (LPR) as the primary cause, or as a significant etiologic factor. Typical symptoms include chronic or intermittent dysphonia (especially in the morning), halitosis, globus, excessive throat mucous, frequent throat clearing, and chronic cough. A frequent complaint of patients with LPR is morning hoarseness that improves as the day progresses. This pattern is not seen in most other conditions causing dysphonia. Surprisingly, most patients with LPR do not present with heartburn, indigestion, or belching—the cardinal symptoms of gastroesophageal reflux disease. Consequently, LPR is often referred to as silent reflux. The pervasive but often overlooked nature of LPR demands that the physician evaluating the dysphonic patient consider this diagnosis in almost every case. The reflux symptom index (RSI) is a nine-item, patient-based outcome instrument that is useful in predicting the likelihood of LPR (Table 2.1) It is easily administered, and highly reproducible. Some degree of reflux is present in normal individuals, and an RSI of greater than 10 is considered abnormal.

Endocrinologic changes can have profound effects on the voice. Many of these changes are reflected in alterations of the lamina propria. An increase in acid mucopolysaccharides in the submucosal tissues of the vocal fold has been demonstrated in an animal model of induced hypothyroidism. This increase draws fluid into Reinke's space osmotically, resulting in edema. The patient may complain of dysphonia, vocal fatigue, muffling of the voice, loss of range, and globus.

Some women report vocal changes associated with the normal menstrual cycle. Most of the adverse effects occur in the premenstrual phase, a phenomenon known as laryngopathia premenstrualis. Slight hoarseness and muffling, vocal fatigue, and loss of the highest notes in the voice characterize this vocal dysfunction. While relatively uncommon in women without formal vocal training, as many as a third of singers report menstrual related dysphonia. In addition, vocal fold varices often increase in size before and during menstruation and have been associated with an increased incidence of submucosal vocal fold hemorrhages.

A few important generalized neurological disorders are characterized by specific patterns of dysphonia. Neurologic disorders resulting in hypoadduction of the vocal folds will present with a weak, breathy voice, vocal fatigue, and an ineffective cough. Such diseases include myasthenia gravis, muscular dystrophy, Parkinson's disease, Shy-Drager syndrome, postpolio syndrome, traumatic brain injury, and abductor spasmodic dysphonia. Hyperfunctional neurologic disorders are associated with a staccato or strained voice. These disorders include adductor spasmodic dysphonia, pseudobulbar palsy, and Huntington's disease. Other neurologic disorders present with mixed ad- and abductor components, making the dysphonia more difficult to diagnose. These disorders include multiple sclerosis, ataxic (cerebellar) dysphonia, and amyotrophic lateral sclerosis. Lastly, vocal tremor can be associated with Parkinson's disease, benign essential tremor, spasmodic dysphonia, and palatopharyngeal myoclonus.

Table 2.2 provides an overview of the historical elements of particular importance when obtaining a voice history. Table 2.3 demonstrates symptoms suggestive of specific voice disorders.

Table 2.1 Reflux Symptom Index

Within the last month, how did the following problems affect you?	0 = No problem 5 = Severe problem
1. Hoarseness or a problem with your voice.	0 1 2 3 4 5
2. Clearing your throat.	0 1 2 3 4 5
3. Excess throat mucus or postnasal drip.	0 1 2 3 4 5
4. Difficulty swallowing food, liquids or pills.	0 1 2 3 4 5
5. Coughing after you ate or after lying down.	0 1 2 3 4 5
6. Breathing difficulties or choking episodes.	0 1 2 3 4 5
7. Troublesome or annoying cough.	0 1 2 3 4 5
8. Sensations of something sticking in your throat or a lump in your throat.	0 1 2 3 4 5
9. Heartburn, chest pain, indigestion, or stomach acid coming up.	0 1 2 3 4 5

From: Belafsky PC, Postma G, Koufman JC (2002) Validity and reliability of the Reflux Symptom Index (RSI). J Voice 16:274–277

2.6 Past Surgical History

A history of prior surgery is important to elicit with laryngeal dysfunction. In addition to questions concerning otolaryngologic procedures, any procedure requiring general anesthesia and endotracheal intubation—even briefly—should be identified. Injuries associated with endotracheal intubation include arytenoid dislocation, vocal process granuloma, vocal fold paralysis/paresis from cuff pressure on the recurrent laryngeal nerves, posterior glottic stenosis, and interarytenoid adhesions.

2.7 Social History

The voice patient's personal habits should be detailed. Even moderate consumption of alcohol is detrimental to the voice, through dehydration and effects on judgment. Caffeine, a diuretic, can affect the voice by thickening secretions and decreasing the efficiency of vocal fold vibration. Certain foods and alcohol predispose to gastroesophageal reflux. The deleterious effects of tobacco smoke on vocal fold are well documented. Both smoke and the heat produced by burning tobacco appear to contribute. Other fumes, such as stage smoke—particularly oil-based ones—can be of significance to vocal performance, especially stage actors.

Table 2.2 Special topics to include within a voice history

Upper respiratory infection
Endotracheal intubation
Time course
Trauma
Voice usage/demands
Profession
Vocal abuse
Tobacco, alcohol, and drug use
Dietary habits
Foods precipitating reflux esophagitis
Hydration
Allergy history
Environmental history
Climate
Heating and cooling units

2.8 Occupational History

Voice disorders affecting vocal professionals have considerably greater impact on function than those affecting nonprofessional voice users. Koufman and Isaacson describe four levels of vocal usage based on occupation. Level I refers to the elite vocal performer such as singers and actors. Level II describes professional voice users such as lecturers and clergy. Level III patients are nonvocal professionals such as teachers and lawyers and level IV users are nonvocal nonprofessionals. Vocal needs and function vary widely among these groups. Although the description of vocal usage is useful as a general categorization, evaluation and therapy must be individually tailored to a person's specific voice use setting and demands.

2.9 Listening to the Voice

A critical part of the clinical evaluation is a careful subjective assessment of the patient's voice. While taking the history, one should evaluate the quality of the patient's speaking voice. The pitch of the voice and the rate and rhythm of speech should be noted. Posture and respiratory rate are important and should be noted during the encounter. Facial movements, especially around the mouth, as well as neck and shoulder movements should be examined for evidence of excess tension, tremors, or spasms. Consideration should be given to efficiency of breath support during speech. Evidence of excess rate, volume, or ten-

Table 2.3 Symptoms suggestive of specific voice disorders

Symptoms	Associated diagnoses
Breathiness	Vocal fold paralysis (unilateral), vocal fold mass lesion
Vocal fatigue	Vocal fold atrophy or paralysis, neurogenic dysphonia
Choking	Vocal fold paralysis, CVA
Odynophonia	Vocal fold granuloma, MTD
Paralaryngeal pain or tension	Muscular tension dysphonia (primary or secondary)
Laryngospasm	LPR, gastroesophageal reflux disease, nerve injury
Stridor	Bilateral vocal fold paralysis, laryngeal stenosis, paradoxical vocal fold motion
Vocal tremor	Parkinson's disease, spasmodic dysphonia, benign essential tremor, myoclonus
Velopharyngeal insufficiency	Myasthenia gravis, ALS, vagal paralysis
Globus	LPR, neurologic disease, MTD

CVA cerebrovascular accident, *MTD* muscle tension dysphonia, *ALS* amyotrophic lateral sclerosis, *LPR* laryngopharyngeal reflux

sion during speech may indicate vocal abuse, which is highly prevalent in the dysphonic population.

After careful patient observation, formal vocal testing may proceed by having the patient perform several different vocal tasks. After hearing normal speech, the patient may be asked to alter his or her type of vocal output, such as hum, sing, whisper, or yell. Also, the patient should alter pitch, perform glissando, and use rapid alternating speech. Such vocal tasks will help the listener gain insight into how the vocal pathology is affecting the different aspects of the patient's speech, and may provide insight into the nature of the vocal dysfunction.

Additionally, various words or sounds call upon the coordination of different phonatory elements. Asking the patient to recite certain phrases will assist the clinician in characterizing the disorder. For instance, the word "taxi" can be used to elicit signs of abductor spasmodic dysphonia. The phoneme "kaa" requires good palatal lift and closure and "maa" requires mouth closure. The /m/ and /n/ phonemes require good nasal resonance and are useful for testing hyper- and hyponasality. The rainbow passage (Table 2.4), which is composed of every phoneme in the English language, is used as a standardized method of recording voice in order to track clinical progress.

2.10 Perceptual Analysis

To evaluate the voice, the "trained" ear remains the most discerning instrument. Nonetheless, a standardized objective, instrument to characterize voice remains an important goal of voice science. To this end, Hirano proposed the GRBAS scale—a widely used perceptual rating instrument used by speech pathologists and laryngologists for the evaluation of voice quality in clinical settings. This scale is a subjective perceptual evaluation of five vocal characteristics assigned a value between 0 to 3, where 0 is normal, and 3 is extreme. The five elements are *grade* (G), a description of the degree of hoarseness, *roughness* (R), the perceptual irregularity of vocal fold vibrations, usually the result of a change in fundamental frequency or amplitude of vibration. *Breathiness* (B), or the assessment of air leakage through the glottis, is the third component of the scale. *Aesthenic* (A) voice denotes weakness and lack of power. *Strain* (S) reflects a perception of vocal hyperfunction.

Another widely used auditory-perceptual evaluation of dysphonia is the Consensus Auditory-Perceptual Evaluation-Voice (CAPE-V) (Table 2.5). This rating scale was recently created by Special Interest Division 3 of the American Speech-Language-Hearing Association as a standardized tool for assessment of auditory–perceptual attributes of voice. Six salient features—overall dysphonia severity, roughness, breathiness, strain, pitch, and loudness—are rated by trained listeners (SLPs and laryngologists) using a 100-mm visual analogue scale for each parameter, with the option for additional user-defined parameters.

2.11 Quality-of-Life Questionnaires

Much work has been performed to codify and measure patient self-perception of vocal dysfunction in the form of standardized questionnaires and other metrics. The voice handicap index (VHI) is a quality-of-life questionnaire specific to voice disorders, which has excellent reliability and reproducibility. The VHI assessment is a subjective patient-based questionnaire composed of 30 questions. Rosen et al. have introduced an abridged version composed of ten questions, the VHI-10 (Table 2.6). This instrument is both easily self-administered and scored quickly at the time of evaluation while preserving the original VHI's utility and validity.

Because vocal pathologies have different levels of handicap to different individuals, these questionnaires are extremely important in understanding the personal impact of these disorders on daily activities. For instance, vocal nodules that are devastating to a professional voice user may only be a minor inconvenience to a non-professional. The Voice-related Quality of Life (VRQOL) instrument has been validated and found to be useful (see Bibliography). Voice-related, patient-based surveys are helpful in judging quickly and accurately the patient's perception of their degree of voice handicap.

2.12 Professional Speaking/Singing Voice

A comprehensive and somewhat adapted historical background is necessary in the evaluation of the singing voice. The date of the next important performance, for instance, will determine whether management of the voice problem can be conservative—designed to assure the long-term protection of the larynx—or, rather, whether more urgent intervention is needed in view of a impending important engagement. The length

Table 2.4 Rainbow passage

When the sunlight strikes raindrops in the air, they act like a prism and form a rainbow. The rainbow is a division of white light into many beautiful colors. These take the shape of a long round arch, with its path high above, and its two ends apparently beyond the horizon. There is, according to legend, a boiling pot of gold at one end. People look, but no one ever finds it. When a man looks for something beyond his reach, his friends say he is looking for the pot of gold at the end of the rainbow.

Passage reprinted from: Fairbanks G (1960) Voice and articulation handbook, p 127. Copyright 1960 by Harper Collins Publishers, Inc.

Table 2.5 Consensus Auditory-Perceptual Evaluation of Voice (CAPE-V)

The following parameters of voice quality will be rated upon completion of the following tasks:
1. Sustain vowels, /a/ and /i/ for 3-5 seconds duration each.
2. Sentence production:
   a. The blue spot is on the key again.
   b. How hard did he hit him?
   c. We were away a year ago.
   d. We eat eggs every Easter.
   e. My mama makes lemon muffins
   f. Peter will keep at the peak.
3. Spontaneous speech in response to "Tell me about your voice problem" or "Tell me how your voice is functioning. "

Legend: C = Consistent I = Intermittent
MI = Mildly Deviant
MO =Moderately Deviant
SE = Severely Deviant

					Score
Overall Severity	MI MO SE		C	I	/100
Roughness	MI MO SE		C	I	/100
Breathiness	MI MO SE		C	I	/100
Strain	MI MO SE		C	I	/100
Pitch	Indicate the nature of the abnormality):				
	MI MO SE		C	I	/100
Loudness	(Indicate the nature of the abnormality):				
	MI MO SE		C	I	/100
	MI MO SE		C	I	/100
	MI MO SE		C	I	/100

COMMENTS ABOUT RESONANCE: NORMAL OTHER (Provide description):

ADDITIONAL FEATURES (for example, diplophonia, fry, falsetto, asthenia, aphonia, pitch instability, tremor, wet/gurgley, or other relevant terms):

of time a singer has been performing is also important, especially if his or her performance career predates their formal vocal training. Undesirable singing techniques developed by amateur singers are particularly difficult to modify. Moreover, intermittent training, or training at the hand of multiple teachers/coaches can often result in an incompatible amalgamation of techniques requiring significant time and expert instruction to rectify. The settings in which the singer performs are of importance. Allergies to dust and mold can become major factors in older concert halls where curtains, backstage trappings, and cramped dressing room quarters are rarely cleaned. This is especially true if stage construction is underway during rehearsals. A history of recent or frequent airplane travel suggests an alternate source of mucosal irritation. Cabin air is dry, usually at 5% or less humidity. Singers must therefore take care to maintain adequate laryngeal moisture by maintaining nasal breathing and constant hydration. Finally, exposure to stage smoke presents a unique problem, most prevalent among stage actors. Most stage smoke preparations, especially oil-based ones, can result in mucosal irritation, allergy, and bronchospasm resulting in the commonly encountered complex of hoarseness, vocal "tickle," and vocal fatigue.