STROBOSCOPY
and High-Speed Imaging of the Vocal Function

SECOND EDITION

Peak Woo, PhD, FACS

Plural Publishing Inc.

PLURAL PUBLISHING
INC.

5521 Ruffin Road
San Diego, CA 92123

e-mail: information@pluralpublishing.com
Website: https://www.pluralpublishing.com

Typeset in 10.5/13 Garamond by Flanagan's Publishing Services, Inc.
Printed in the United States of America by by Integrated Books International

NOTICE TO THE READER
Care has been taken to confirm the accuracy of the indications, procedures, drug dosages, and diagnosis and remediation protocols presented in this book and to ensure that they conform to the practices of the general medical and health services communities. However, the authors, editors, and publisher are not responsible for errors or omissions or for any consequences from application of the information in this book and make no warranty, expressed or implied, with respect to the currency, completeness, or accuracy of the contents of the publication. The diagnostic and remediation protocols and the medications described do not necessarily have specific approval by the Food and Drug administration for use in the disorders and/or diseases and dosages for which they are recommended. Application of this information in a particular situation remains the professional responsibility of the practitioner. Because standards of practice and usage change, it is the responsibility of the practitioner to keep abreast of revised recommendations, dosages, and procedures.

Library of Congress Cataloging-in-Publication Data:
Names: Woo, Peak, author.
Title: Stroboscopy and high-speed imaging of the vocal function / Peak Woo.
Description: Second edition. | San Diego, CA : Plural Publishing, Inc., [2022] | Preceded by Stroboscopy / Peak Woo. c2010. | Includes bibliographical references and index.
Identifiers: LCCN 2021017797 (print) | LCCN 2021017798 (ebook) | ISBN 9781635502367 (hardcover) | ISBN 1635502365 (hardcover) | ISBN 9781635502503 (ebook)
Subjects: MESH: Vocal Cords—physiopathology | Stroboscopy—methods | Laryngeal Diseases—diagnosis | Vocal Cords—physiology
Classification: LCC QP306 (print) | LCC QP306 (ebook) | NLM WV 530 | DDC 612.7/8—dc23
LC record available at https://lccn.loc.gov/2021017797
LC ebook record available at https://lccn.loc.gov/2021017798

Contents

Foreword by Thomas Murry *xi*
Preface *xiii*
Acknowledgments *xv*

PART I. BASIC SCIENCE AND INTRODUCTION

1. History of Stroboscopy and High-Speed Imaging of Laryngeal Vibration **3**
History of Stroboscopy and High-Speed Video 3
References 5

2. Principle of Stroboscopy **7**
Stroboscopy and Talbot's Law 7
References 14

3. Anatomy of the Larynx and Histology of the Vocal Folds **17**
Laryngeal Framework and Skeleton Cartilage 18
Hyoid Bone 20
Thyroid Cartilage 21
Cricoid Cartilage 23
Arytenoid Cartilages and Epiglottis 25
Fascia, Ligaments, and Joints of the Larynx 25
Anatomic Regions of the Larynx 28
Muscles of the Larynx 29
Extrinsic Muscles 29
Cricothyroid Muscle 31
Thyroarytenoid Muscle 31
Posterior Cricoarytenoid Muscle 32
Lateral Cricoarytenoid Muscle 32
Interarytenoid Muscle 33
Structure of the Vocal Folds 33
Pathology and the Involvement of the Vocal Fold Layers 35
References 38

4. Vocal Fold Vibration and Phonatory Physiology **41**
Criteria for Normal Vocal Fold Vibration 41
Normal Vibratory Behavior of the Vocal Folds 43
The Glottal Cycle 44
Acoustic and Aerodynamic Interactions With Vocal Fold Vibration 49
The Larynx as DC to AC Airflow Converter 50

Mass Effects on Vocal Fold Vibration 52
Effect of Stiffness on Vocal Fold Vibration 52
Effect of Tension Change on Vocal Fold Vibration 53
References 54

5. Videokymography and High-Speed Digital Imaging of the Larynx 55
Disadvantages of Videostroboscopy 55
Videokymography 56
High-Speed Video Imaging of Vocal Vibration 58
Normal Onset and Offset of Vocal Fold Oscillation 59
Clinical Application of High-Speed Imaging in Diplophonia 59
References 62

6. Normal Phonation and Vocal Fold Vibration 65
Dynamic Changes in the Glottal Cycle 65
Gender Differences 78
Age Differences 79
Intensity and Amplitude Modulation 80
Pitch Modulation 87
Intensity Modulation 90
Pitch and Amplitude Modulation Interactions 92
References 92

7. Abnormal Vocal Fold Vibration 95
Introduction 95
Tension Abnormality 100
Increase in Tension of the Vocal Fold Ligament 102
Stiffness Abnormality 104
Glottal Closure and Level Difference 108
Unilateral Versus Bilateral Effects of Mass, Tension, and Stiffness 111
References 113

8. Instrument and Clinical Operation 115
Introduction 115
Stroboscope Versus High-Speed Imaging of Vocal Fold Vibration 116
Use of Stroboscopy 117
Documentation 117
Clinical Care in Laryngology and Voice Care 117
Phonation Research 120
Image Processing and Automation 122
References 123

9. The Clinical Examination Using Videostroboscopy 125
The Examination Room 125
Patient's and Examiner's Positions 126

Equipment Considerations 127
The Stroboscope 128
Videos and Cameras 130
Imaging Management 132
Endoscopes: Rigid, Fiberscope, and Videoendoscopes 132
Who Is Doing the Examination and What Is the Stroboscopy Data Being Used For? 137
Otolaryngologist Versus Speech Pathologist 137
Laryngoscopy Versus Phonoscopic Examination 137
References 140

10. Stroboscopy Setup and Recording 143
Introduction 143
Rigid Endoscopic Examination 149
Performing the Examination 154
Anesthesia for Rigid and Flexible Laryngoscopy 154
Tokens Sampled During the Stroboscopy Examination 155
Avoiding the Pitfalls of Stroboscopy 156
Artifacts 156
References 157

11. Avoiding Errors During Stroboscopy 159
Recording Artifacts 159
Closure Problems 160
Open Phase Predominates and Errors Related to Their Interpretation 161
Glottic Configuration Abnormalities 163
Phase Shift Findings During the Production of Falsetto 163
References 164

12. Interpretation of Videostroboscopy 167
Introduction 167
Normal Variations 167
Phase Shifts at Falsetto and Flute Register Are Normal 167
Interpretation of the Stroboscopy Examination 168
Fundamental Frequency 168
Periodicity of the Vocal Fold Oscillation 170
Phase of Vocal Closure During Modal “ee” Phonation 171
Phase Symmetry 174
Configuration of Glottic Closure 176
Vocal Fold Edge 183
Amplitude 183
Mucosal Wave 184
Nonvibrating Segment 187
Synthesis of the Clinical Voice Disorder 188
References 189

PART II. LARYNGEAL DISORDERS

13. Laryngeal Inflammation **193**
Acute Inflammation 193
Chronic Laryngitis 204
Radiation Laryngitis 209
Reflux Laryngitis: Acute and Chronic 210
Candida Laryngitis 215
References 216

14. Granulomatous Diseases of the Larynx **221**
Granulomatous Laryngitis 221
Rheumatoid Nodules and Autoimmune Deposits of the Larynx 225
References 228

15. Granulation and Contact Granuloma **231**
Contact Ulcer, Granulation Tissue, and Intubation Granuloma 231
Pathophysiology/Histology 231
Risk Factors and Populations 234
Physical Examination 235
Differential Diagnosis 238
Treatment and Management 239
References 239

16. Laryngeal Trauma **241**
Introduction 241
Arytenoid Dislocation 245
Laryngeal Stenosis 250
References 256

17. Vocal Fold Scar **259**
Introduction 259
Rehabilitation Strategies for Vocal Fold Scar 268
Prevention of Vocal Fold Scar 268
Surgical Treatment in the Management of Scar 270
References 270

18. Benign Mucosal Lesions **273**
Introduction 273
Nodules 279
Polyps 289
Hemorrhagic Polyps 290
Polypoid Corditis/Reinke's Edema 298
Laryngeal Edema 300

Cysts 301
  Pseudocyst and Fibrovascular Lesion 306
Microwebs 309
Vascular Ectasia 309
  Acute Vocal Fold Hemorrhage 312
Sulcus Vocalis 313
Mucosal Bridge 322
References 323

19. Premalignant Lesions and Lesions of Uncertain Behavior 327
References 334

20. Malignant Neoplasms of the Larynx 335
References 339

21. The Aging Voice 341
References 346

22. Benign Tumors and Nonneoplastic Masses of the Larynx 349
Laryngeal Papillomas 349
Verrucous Lesions of the Larynx 353
Other Reactive Lesions 356
  Internal and External Laryngoceles, Saccular Cysts 356
References 357

23. Vocal Fold Paralysis and Vocal Fold Paresis 359
Introduction 359
Signs and Symptoms 361
Voice Quality of Unilateral Vocal Fold Paralysis and Paralysis 361
Recurrent Laryngeal Nerve Paralysis and Paresis 362
  Paralysis Versus Paresis 369
  Role of Stroboscopy in Treatment Planning for Vocal Fold Paralysis and Paresis 369
Superior Laryngeal Nerve Paralysis 372
Combined Laryngeal Nerve Paralysis 375
Vocal Fold Paresis 375
References 379

24. Irritable Larynx Syndrome 385
References 387

25. Neurogenic Dysphonia 389
Spasmodic Dysphonia 389
  Vocal Tremor 393
Neurogenic Diseases 394
References 395

26. Functional Dysphonia and Muscle Tension Dysphonia **399**
References 406

27. Stroboscopy in the Management of Phonosurgery **409**
Introduction 409
Preoperative Analysis of the Lesion Before Surgery 409
Intraoperative Use of Videostroboscopy 411
Postoperative Use of Stroboscopy in Analyzing Phonosurgery Results 411
References 414

Index *417*

Foreword

I am delighted to write the Foreword for the second edition of *Stroboscopy and High-Speed Imaging of the Vocal Function* by Dr. Peak Woo. Dr. Woo and I have known each other and have followed each other's work since his residency at Boston University and my post-doctoral fellowship at the University of Florida. We met through my doctoral laboratory partner, Ray Colton, who invited me to Syracuse University shortly after Dr. Woo joined the Upstate Medical Center faculty and the Syracuse University Voice Center. Throughout the years, we have developed a professional relationship and friendship centered on the education, diagnosis, treatment, and research of the voice. He has been instrumental in working with me as well as with other speech-language pathologists to advance the diagnosis and treatment of voice disorders through his lectures and publications. This is a book that otolaryngologists, speech-language pathologists, singers, and others who have an interest in the voice will want.

In this book, the reader, whether an otolaryngologist or speech-language pathologist, will appreciate Dr. Woo's knowledge of laryngology, the importance of stroboscopy as a diagnostic tool, and his thorough approach to stroboscopic interpretation. Dr. Woo brings his ability as a teacher to share his knowledge of stroboscopy and its role and importance in the diagnosis and treatment of voice disorders.

In the first edition, Dr. Stanley Shapshay shared some of Dr. Woo's unique characteristics as a physician, scientist, colleague, and educator. My own experience interacting and collaborating with Dr. Woo has led me to a better understanding of the physiology and pathology of the voice. Dr. Woo is enthusiastic about the voice, whether it be on a Saturday morning in his office, on a bus ride in Paris, or at breakfast in one of his favorite restaurants in New York City. He has the ability to challenge himself as well as others, to develop new ideas and pose questions that open new pathways and uncharted areas of study. Speech pathology colleagues, residents, and his fellow otolaryngologists find him to be an excellent teacher. When Kay Pentax still offered stroboscopy courses, Dr. Woo's courses were full and his audience of otolaryngologists and speech-language pathologists was eager to learn stroboscopic interpretation even after 5:00 p.m. on a Saturday evening. In this book, Dr. Woo uses video examples of the vocal folds to guide the reader on how to use stroboscopy as a diagnostic tool and determine a treatment plan.

The book is divided into two parts: Part I, Basic Science and Introduction, and Part II, Laryngeal Disorders. In Part I, Dr. Woo presents a historical narrative of stroboscopy and visualization of the larynx from the 19th century to the present. His description outlines the evolution of stroboscopy from its early beginnings in the 19th century to the present-day digital, miniaturization, and development of endoscopes to achieve high-quality visual evidence of vocal fold movements. Dr. Woo stresses the importance of reaching a diagnosis and treatment plan by evaluating the stroboscopic examination along with obtaining measures of vocal function. Part I serves as a textbook for understanding vocal fold motion in normal and pathological voices. Importantly, he reminds the reader that although obtaining a stroboscopic image is not too difficult, interpreting the image is an art that comes from mentorship and experience. He completes Part I with clear descriptions of the stroboscopic technique and the interpretation of the images obtained. Throughout this part of the book, elegant images of the vocal folds are abundant. A new chapter on high-speed video endoscopy is a testimony to the level of leadership in vocal fold imaging that Dr. Woo has strived for in trying to improve diagnostic accuracy.

In Part II, the clinical section of the book, the importance of the role of stroboscopy in providing visual imaging of the vocal folds is highlighted. Dr. Woo has included additional montages of stroboscopic examinations to point out details that may be missed on regular video viewing but that are essential in reaching a diagnosis. He has also added illustrative examples of glottal configurations to stress the importance of the types of vocal fold movements and closure patterns related to conditions such as vocal fold scarring and aging voices. With each chapter, the reader will see how Dr. Woo reaches a diagnosis by combining the case history with the stroboscopy findings. His discussion on glottic insufficiency in Chapter 23, along with the illustrations and stroboscopic examples, provides a comprehensive workup of vocal fold paralysis.

In this edition, Dr. Woo brings stroboscopy to life with video examinations that accompany the text. Both stroboscopic examinations and high-speed video examples of exact vocal fold motion can now be seen accompanied by detailed descriptions. His use of video examples provides an additional level of education regarding the details of vocal fold motion. He has compiled more than 450 citations, including many from 2020, for readers to further their investigation of voice disorders and diseases.

In summary, in the second edition of *Stroboscopy and High-Speed Imaging of the Vocal Function*, Dr. Woo brings new information to the study of the voice through his expertise in stroboscopy, including the techniques to obtain the best video images and to interpret these images. He demonstrates that stroboscopy is one of the clinician's most relevant working tool. More important, he combines the role of stroboscopy with how the tool is used for teaching, patient education, diagnosis, and research. Dr. Woo's passion for the study of the voice, his unique expertise, and his talent for sharing his knowledge with others have allowed him to write a textbook that is enjoyable to read and provides a wealth of new visual information about the art and science of the larynx. Dr. Woo also stresses throughout the book that due to the constant improvement in stroboscopy and the unique collaboration between the otolaryngologist and the speech-language pathologist, we have gained a better understanding of the voice and its disorders. Finally, he challenges us to continue to improve our understanding of the human voice by continually seeking innovative technologies, asking thought-provoking questions, and pursuing collaboration among voice professionals.

Thomas Murry, PhD
Professor, Otolaryngology Head and Neck Surgery
Loma Linda University Health
Loma Linda, California

6 Normal Phonation and Vocal Fold Vibration

DYNAMIC CHANGES IN THE GLOTTAL CYCLE

The normal vocal folds are capable of multiple vibratory patterns. The clinician faced with the dysphonic patient must target adequate samples to get a representative idea of vocal vibration capability yet the examination should be brief enough to be performed in a typical office setting within the time constraints of a consultation. One can have many different protocols for the examination of the dysphonic patient. Tailoring the examination complexity to the suspected pathology will give the greatest yield. A simple examination would investigate vocal fold vibratory behavior in patients suspected of having vocal fold lesions. A complex voice protocol would investigate complicated or subtle dysphonia in singers and voice professionals. Because the larynx is capable of many different changes depending on pitch, loudness, mode of vibration, and gender, it is important for the examiner to have an appreciation of the differences in normal individuals in order to examine and diagnose a pathologic condition.

The three primary types of vibration of the vocal folds have been termed registers of the voice. Figures 6–1, 3–12, and 4–9 are video montages of a glottal cycle in modal phonation, falsetto, and vocal fry. Each of the samples is done with the loudness at approximately 75 dB. One can clearly see differences and similarities by viewing these three montages together. With different registers, the vocal folds assume specific configuration of vibratory pattern. The three primary register patterns are chest register, head register, and vocal fry register. The configurations of the larynx and the glottal edge vibration tracings are shown schematically in Figure 4–10. In the analysis of singing capability, a fourth register is described as a flute register. The flute register is of primary interest in singing assessment and is not described as much as the primary three registers.

The most common and easiest to produce mode of phonation is the chest register. This is called modal phonation. In this mode of phonation, the vocal folds are at their most relaxed, the subglottic pressure used to drive the fold is the least, and the tracing (middle, Figure 4–10) shows there is the largest amplitude of the three registers. In the chest resister, the glottis aperture above the fold is usually round, and the vocal folds are neither thin as in falsetto nor thick as in vocal fry. The glottal cycle tracing shows there to be a distinct opening, closing, and closed phase. The opening and closing phases are smooth and roughly equal in duration. The opening of the vocal fold is about the same duration as the closing of the vocal fold. The duration of the open phase compared to the whole glottal cycle is approximately 50% to 60% of the glottal cycle. The duration of the closed phase is approximately 40% to 50% of the glottal cycle.[1]

With falsetto voice, the vibratory character changes. The vocal fold is thinner and vibrates with thinned, long vocal folds (top, Figure 4–10). In the falsetto register, the supraglottis laryngeal configuration is oval with a long anterior to posterior axis. This is due to the contraction of the cricothyroid muscle that elongates and thins the vocal folds. The vocal folds are thin and oscillated with lower amplitude compared with modal voice. The open and closed phases are now fused into one sinusoidal pattern that does not completely close the glottal

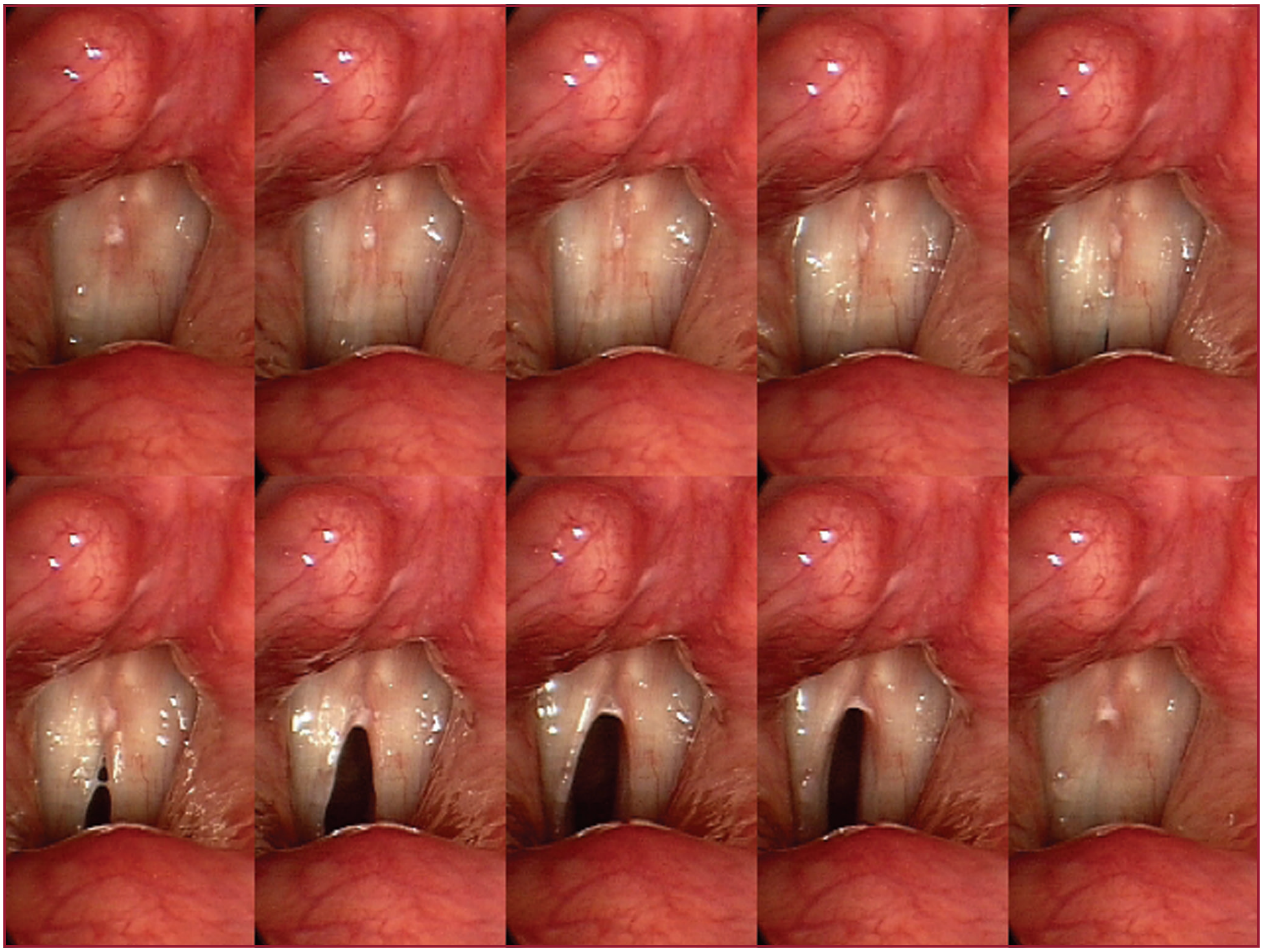

Figure 6–1. Modal phonation, 110 Hz, 75 dB output. Modal voice is being produced at 75 dB but held at the frequency of 110 Hz. The glottal cycle is open approximately 50% of the cycle and in contact in 50% of the cycle. The amplitude of excursion from each side is symmetric with evidence of complete closure. The mucosal wave is now clearly visible as a traveling wave on the superior surface of the vocal fold.

aperture. The open phase dominates the entire glottal cycle with a sinusoidal pattern of oscillation. There is no closed phase. The two opposing edges of the vocal folds usually do not completely touch with falsetto register production.

Vocal fry usually is not used or rarely used during normal phonation. This is also termed the pulse register. This is because individual pulses of air are audible during the production of vocal fry. To produce the vocal fry sound, the vocal folds must be short and thick. The vocal folds position is produced by contraction of the thyroarytenoid muscle. This type of phonation will result in a flattened, oval-shaped laryngeal introitus with the long axis in the lateral to medial direction (Figure 4–10, bottom). On the glottal waveform tracing, the closed period dominates with a brief opening and a prolonged closed phase. Because the vocal folds are usually tightly approximated during the pulsed register, the amplitude of vibration is low.

The ability to produce different registers is largely a result of differential activation of the intrinsic muscles of the larynx. If the vocal fold is placed in a thin, elongated configuration by the contraction of the cricothyroid muscle, the thin vocal folds will oscillate as a sinusoidal pattern.[2] If the thyroarytenoid muscle is contracted with very little activation from the cricothyroid muscle, the vocal fold will be short and adducted.[3] In modal voice or chest register where there is a balance of both airflow and cricothyroid and thyroarytenoid muscle activity, the vocal folds will oscillate in steady phonation, termed the modal register.[4,5]

Instead of looking at the video of vocal fold vibration, a simpler way to document and analyze vocal fold vibration is to print a series of images representative of the glottal cycle. Figure 6–2 is a photo montage of a normal male phonating "ee" at 234 Hz and 77 dB output. Figures 2–3, 4–5, and 6–1 show three photo montages of the glottal cycle from a single subject phonating at 125 Hz and 77 dB output, 124 Hz and 71 dB output, and 234 Hz and 77 dB output, respectively. One can make several observations about the change in vocal vibratory function as the voice quality is altered by frequency and loudness. Because chest register voice is the most easily produced and most easily sustained, this is the most commonly used token for testing of abnormalities of the spoken voice. The voice is produced at a most comfortable pitch and loudness. This modal voice is the most common token used for analysis of vocal vibratory function. In each of the montages, 10 frames of vocal folds are evaluated as they go from completely closed to open and then back to a completely closed position. These 10 frames of video constitute a single glottal cycle. During the production of modal voice in normals, the vocal folds open and close in a smooth ascending and descending pattern. When the vocal folds have come into contact, they stay in contact for a number of frames. During the production of modal voice, the open phase roughly equals the closed phase. The opening phase roughly equals the laryngeal closing phase. The transition from frame to frame in terms of the open glottal area is smooth and shows smooth symmetric progressions until the vocal folds have reached the maximal open condition. Each vocal fold oscillation is mirrored by the opposite side.

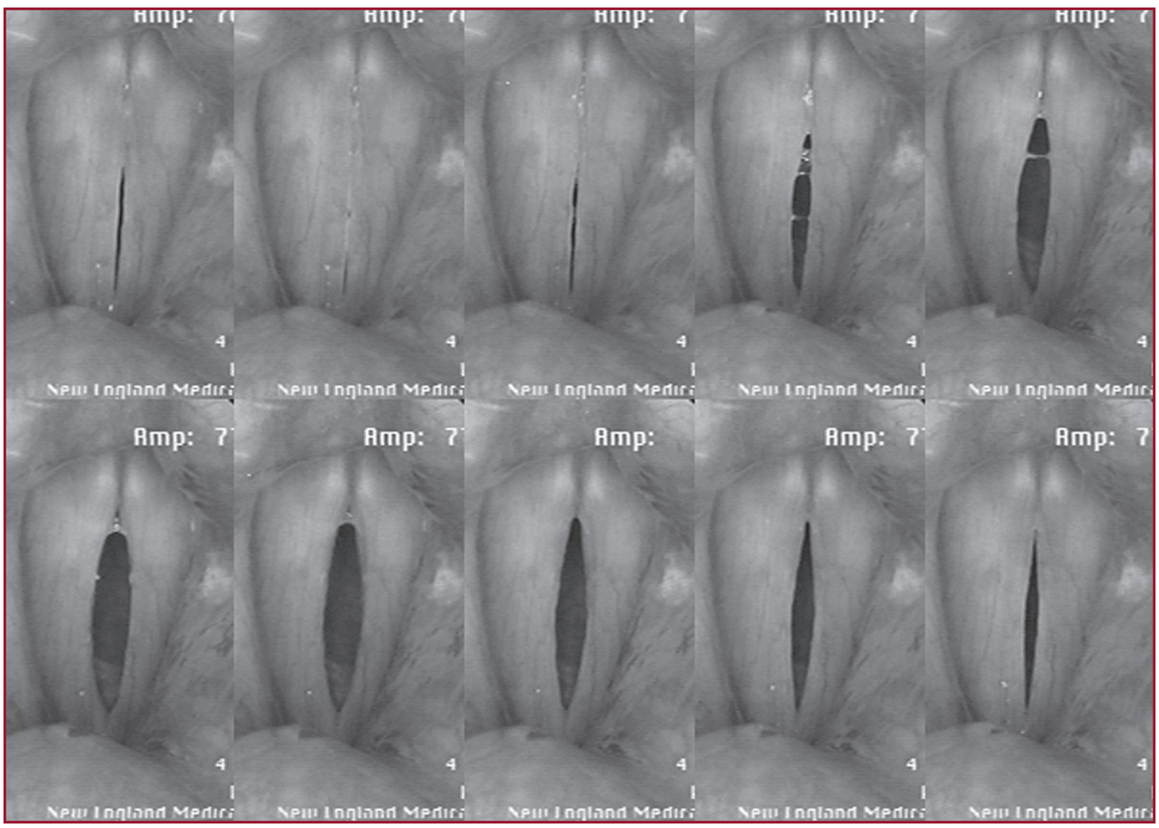

Figure 6–2. The stroboscopy image of a glottal cycle produced by a male at 234 Hz and 77 dB.

As the vocal folds open and close together, they are said to be vibrating in phase. This in-phase vocal fold oscillation is repeated from cycle to cycle. The point of maximal vibration is in the midmembranous vocal fold area. To analyze the trajectory of vocal fold oscillation from cycle to cycle, we can plot the trajectory of the midmembranous vocal fold against the frame number of the stroboscope video to look at the function of each vocal fold relative to the other. One such plot of this series is shown from high-speed video recording in Figure 6–3. This is a kymography plot. This trajectory of the midmembranous vocal fold is derived by plotting the vocal fold margin at the midmembranous vocal fold across the series of glottal images. This plot is from the high-speed video image, but it may also be done from the stroboscopy video. The right vocal fold excursion goes upward in the positive direction while the negative deflection represents the excursion of the left vocal fold. Time is shown on the *x*-axis and represents the frames of the video. Image analysis software also can perform automated edge detection and plot the glottal area defined by the vocal fold margin as the glottal area waveform (GAW). The glottal area plot is shown on Figure 6–3 in yellow. In Figure 6–3, the plot shows three lines. This plot has the trajectory of the vocal fold on the right and left for four glottal cycles. This is represented by the mirror images of the up and down motion representing the right (up) and left (down) vocal folds. The yellow tracing and area is the GAW, which is a summation of the pixels (shown in black) detected during each glottal cycle. To calculate the GAW image, one can trace the vocal fold margin from the cinematography picture and summarize the area for each frame. Fortunately, it is possible to do this using image analysis techniques. Figure 6–4 is the montage from a high-speed video for which the computer software automatically traced the glottal area for three glottal cycles. From the tracings, the computer has done a good job of tracing the glottal area, and the area is summated versus the frame number. This is the GAW. Graphic analysis is an easy way to analyze motion of vocal folds any-

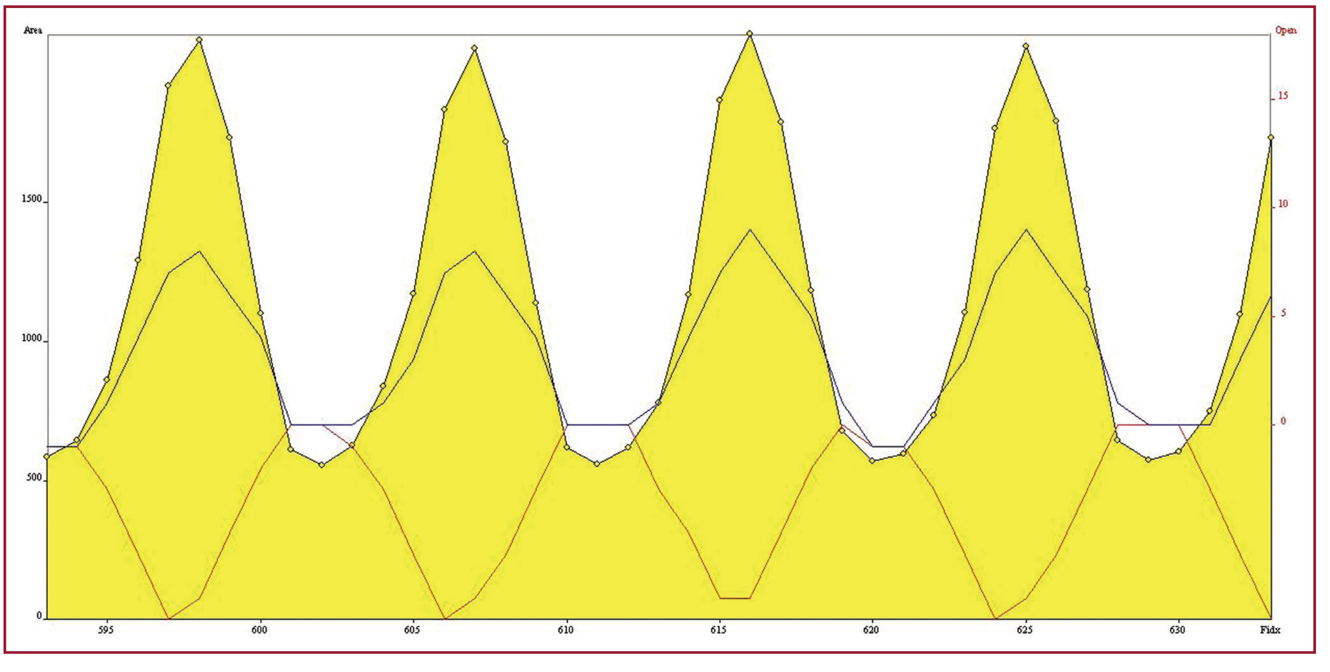

Figure 6–3. The glottal area waveform (GAW) for modal "ee" is the area at the top of each tracing shown in yellow. The areas to the right and left of each tracing indicate the change in pixels off the midline for each fold. The GAW is the summation of the area change. When each vocal fold is a mirror image of the other, the area will the summed up as a large well-defined GAW plot. The summated GAW is on top. *y*-axis = pixel value; *x*-axis = frame number.

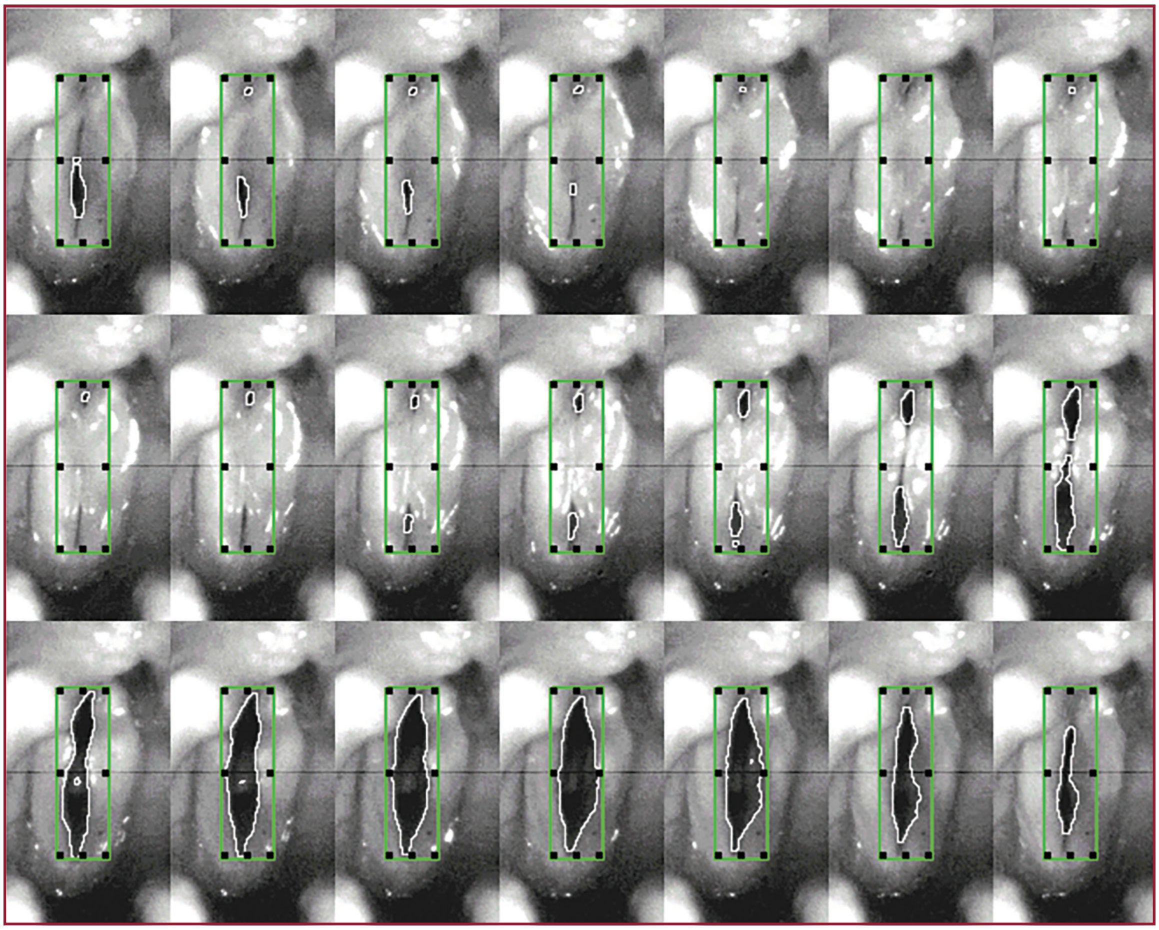

Figure 6–4. Using edge detection, the software automatically traces the glottal margin and calculates the number of pixels of each frame that corresponds to the glottal area for that video frame. The total number of pixels in the dark for each frame is plotted by the video frame to calculate the glottal area waveform.

where along the length of the membranous vocal fold as well as map the change in the glottal area during the glottal cycle. This type of analysis can be done for either stroboscopic images or high-speed video images.[1,6–8]

During modal phonation, the vocal folds are approximated and not very tense. Oscillation of the superficial layer of the lamina propria will result in a propagation of the mucosal wave moving independently from that of the vocal ligament and the muscles. There is a separation of the body from the cover. Because there is also an oscillation of the upper and the lower lip, there is a phase difference between the upper lip of the vocal fold and the lower lip. This phase difference between the upper and lower lip is best seen on modal phonation. Furthermore, as the vocal folds open, there is a mucosal wave that is propagated across the superior surface of the vocal fold. This mucosal wave is actually propagated from the undersurface of the vocal fold. As observers from the top down, we can only appreciate the mucosal wave starting from the vocal fold margin and propagating across the superior surface of the vocal fold. Figure 6–5 is a single frame from a normal subject sustaining a loud voice in chest voice. It shows the normal phase difference in the upper and lower lip of the vocal fold. One can see that as the upper lip is still opening, the lower lip is closing in. This is because the upper and lower lip of the vocal fold in modal voice behave differently

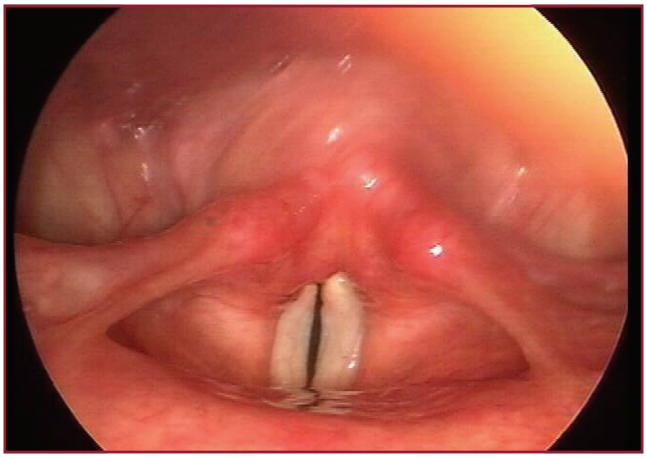

Figure 6–5. Phase difference between the upper lip of the vocal fold and the lower lip in loud chest voice. During loud phonation, the upper lip of the vocal fold may still be going outward while the lower lip is already coming inward. Loud phonation accentuated the normal vertical phase difference and is one of the ways to inspect the lower lip of the vocal fold by stroboscopy.

such that there is closure of the inferior lip of the vocal fold while the upper lip is still opening and propagating the mucosal wave. Figure 6–6 is a montage of video frames from a videostroboscopy showing one glottal cycle. This is done for a male phonating at modal pitch and loudness. The capture of this video montage takes every other video frame of the stroboscopy with a display of 20 video frames per glottal cycle. In this way, the 10 pictures shown in this montage are representative of the glottal cycle. This is a convenient way to summarize the glottal cycle using a photo without the need to have the video. Video 6–1 is the stroboscopy video of a male phonating at modal pitch and loudness. When the voice is periodic, the video stroboscopy can track the frequency well and the vocal fold appears to vibrate in slow motion. This upper and lower vocal fold vibration phase difference allows the examiner to evaluate the status of the closing of the lower lip of the vocal fold while the upper lip is still lateralized. This phase lag between the upper and lower lip of the vocal fold is very important in modal voice phonation and has important implications in looking for lesions that may reside only on the undersurface of the vocal fold. Knowing how the normal phase difference exists in modal voice allows the examiner to analyze the normal layered structure of the vocal fold during phonation.

During falsetto or head voice, the vocal fold configuration is changed as a result of the increased contraction of the cricothyroid muscle. The increased tension of the vocal fold by stretching of the vocal ligament is translated into a much thinner lamina propria with a longer vocal ligament. Thus, during falsetto voice, the mass of the vocal fold is reduced. The tension and the stiffness of the vocal fold are greater due to increased tension on the vocal ligament. This results in a sinusoidal vibratory pattern. Figure 4–10 is an illustration of the kymography tracing for falsetto voice, chest voice, and vocal fry voice. Comparing the video of modal phonation to falsetto, the most obvious finding is that the vocal folds are much longer and the degree of lateral movement of the vocal fold with each glottal cycle is much less in falsetto voice than in modal voice. From the kymography display (see Figure 4–10), additional observations may be made. In falsetto, each glottal cycle oscillates at a higher frequency than during the production of modal voice. The vocal folds continue to have both an opening and a closing phase, but the closed phase is absent. The vocal folds may not touch at all during each cycle. The falsetto voice has a higher frequency, it is sinusoidal in vibratory pattern, and it does not necessarily come in contact with the opposite vocal fold. The folds continue to oscillate in phase relative to the contralateral vocal fold. Unlike the modal voice phonation pattern, there is no longer glottal contact and the closed phase is absent. The glottal cycle consists of the opening and closing phase of the glottal cycle without a distinct closed phase. The greatest lateral excursion of the vocal fold in falsetto is less than that of the modal voice pattern. In falsetto voice, the mucosal wave propagation is smaller compared to that of modal voice. Also, during falsetto voice, there is no longer a phase lag between the upper and lower lip of the vocal folds. The vocal fold vibrates as a single unit. There is no longer a visible difference between the vibratory behavior of the upper lip of the vocal fold and that of the lower lip of the vocal fold. The vocal folds oscillate as a single body that opens and closes. Unlike modal voice phonation, the vocal folds oscillate as a string-like oscillation. It has a a sinusoidal excursion pat-