A Practical Guide to Laryngeal Framework Surgery

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Edited by Sharat Mohan, Kate Young, and Owen Judd

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Dedicated to our children:

Megha, Max, Toby, Sophie

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Foreword

Laryngeal framework surgery has been at the centre of surgical management for the immobile and/or paralysed vocal fold since its development by Professor Isshiki in the 1970s. However, in recent years in the UK there has been a subtle shift in the management paradigm for vocal fold immobility from early speech therapy followed by a 'wait and see' approach, with framework surgery as the fallback, to early surgical intervention with injectable materials.

A corollary to this resurgence of interest in laryngeal injection has been a proliferation of courses designed to improve surgical competency in laryngeal injection approaches. One could easily foresee a day in the not-too-distant future in which facility and comfort with procedures utilizing injection techniques could relegate laryngeal framework procedures to the back cupboards of the armamentarium of the modern laryngologist and off the curriculum of the laryngological trainee.

This would be a substantial error. Laryngeal framework surgery has a proven evidence base for improvement in our patients' voice outcomes. Facility with framework surgery has led to a fundamental increase in our understanding of laryngeal structure and function. It is my opinion that such facility needs to remain at the very heart of laryngological education and training.

So, for the practising laryngologist, what approach to use, when to use it, and how? This practical guide, I am pleased to state, addresses these queries. It offers a detailed guide to just about every aspect of laryngeal framework surgery that the contemporary laryngologist could have whilst also supplying useful information on injection techniques. There are chapters on such areas as medialization thyroplasty, arytenoid adduction, cricothyroid approximation, laryngeal resizing for voice feminization, relaxation thyroplasty, lateralization procedures, and, yes, a chapter on injection laryngoplasty. There are chapters on history and on the future, chapters on clinical assessment, speech therapy, and anaesthesia.

It is my expectation that the reader will find him or herself reaching for this practical guide on a regular basis. I wish each of you an enjoyable read, and hope that this little gem of a book proves invaluable to your surgical practice.

John Rubin, MD, FRCS, FACS

Foreword

Exactly 100 ago in 1915, Payr published an article on a technique for medialization laryngoplasty that he had performed. The operation demonstrated that a small procedure can produce a substantial improvement in voice. During that same period (1911), Brünings published his approach to augment an immobile vocal fold in a patient with unilateral vocal fold paralysis. So, after 100 years and after a surge of phonosurgical articles and textbooks over the last 30 years, why come up with a new textbook and guide for laryngeal framework surgery and phonosurgery?

Well, even though volumes have been written about techniques for vocal improvement, specialists in our field still have the impression that these techniques are not used as frequently as they might be. Perhaps one answer lies in the assumption that phonosurgery is too complicated, or phonosurgical learning curves might be too steep and younger colleagues become demotivated or even frightened. If so, there should no longer be any excuses for not performing phonosurgical procedures. It is to the credit of the authors of this practical guide that they have sought to eradicate these inhibitions and restraints by showing us that phonosurgery in a clinical setting, with all of the prerequisites from diagnosis, anesthesia, post-operative follow-up, can be managed and how this may best be achieved.

Usefulness and practicality, together with detailed recommendations, is what beginners require. The editors have succeeded in presenting a book that is comprehensive enough to offer much practical information to the interested reader, while keeping the format of the guide portable. The task-specific chapters on techniques are really well laid out – they are short, to the point, and include tips and tricks. The chapters are very well illustrated with many figures, and the references offer a quick link to more detailed literature for the interested reader. The authors have done their best to share from their own experience, and have not excluded addressing potential risks, or avoiding mention of possible complications – and how best to deal with them.

This is an excellent piece of work for motivated colleagues who are willing to go the extra mile into this exciting and expanding field of phonosurgery.

Markus Hess, MD

Preface

On the evening of my retirement party, a colleague of mine pulled me to one side and whispered to me, "Sharat, you must write a book on voice surgery. You and Kate together have years of experience in this field. It should not be wasted."

I said, "We have already done some work on this; thanks for the idea."

I came home and gave it some serious thought. I thought, I will write up whatever work I have done with Kate. I discussed this with my fellow editors, Kate and Owen, and they were both positive. We started contacting people and at some point in time, this guide 'evolved'!

The response from potential contributors was excellent. The icing on the cake was when Kate called and said she had spoken to Markus Hess, whom we had met in London a few years before, and he not only agreed to write a Foreword to the book, but also expressed an interest in contributing a chapter. In addition to Dr Hess, we are all extremely thankful to John Rubin who wrote the other Foreword for us, and was always very supportive of our work.

Our book begins with an introduction and European Classification by Declan Costello and Owen Judd. It highlights the fact of how vital voice is in all age groups – children, professionals, and the retired – and stresses its economic impact on society. It also covers relevant history, including early publications, laryngoscopic techniques, laryngeal diseases, and treatments for vocal fold weaknesses.

The next chapter, also by Owen and Declan, details the anatomy and physiology of the larynx, featuring diagrams of the gross anatomy and histology of the vocal fold and the physiology of the mucosal wave. There is an extremely good table on the intrinsic muscles of the larynx and their actions, which was always difficult for me personally to learn as a medical student in the 1970s!

Following this, Julian McGlashan, nicely complements the previous chapter in his discussion on objective assessment and the principles of stroboscopy. He explains methods of examination and equipment in the voice clinic, the importance of digital recordings, techniques and protocols of examinations. The chapter also covers high speed digital imaging and diagnostic microlaryngoscopies. Julian also explains special situations, such as assessment of children

and singers. This is a very informative chapter for doctors and speech therapists in setting up a joint voice clinic.

After this, Kate Young and Jane Shaw explain the role of speech therapists in laryngeal framework surgery. In our practice, the speech therapist has a major role and we started a trend in the UK that the speech therapist is physically present in the operating theatre for a medialization thyroplasty, as an un-scrubbed available clinician. This is very important for 'voice trials', when the surgeon places the implant under local anaesthesia. I personally have never operated on a patient without consulting and involving my speech therapist.

This chapter also explains the importance of observing the patient on the day of the procedure (in cases of injection laryngoplasty as an outpatient procedure), management of suboptimal outcomes, and long term follow-up. This is a must read chapter for surgeons and speech therapists alike.

Though the majority of laryngeal framework surgery is performed using local anaesthesia, we always had an anaesthetist in the operating theatre. The chapter on anaesthesia by Navneet Narula and A. Philip explains the importance of being aware of the initial pathology that has prompted the need for laryngeal framework surgery. It also emphasizes the residual effects causing altered laryngeal and pharyngeal anatomy, sensation, and potential effects of chemotherapy or radiotherapy. The chapter also explains issues relating to smokers, highlights the importance of suppression of airway reflexes, the cooperation of the sedated patient, awake enough to phonate on command, and, most importantly, how to approach sharing the airway with the surgeon.

It explains local anaesthesia with target controlled sedation, general anaesthesia (GA) techniques with microlaryngeal tubes (MLT) and laryngeal masks (LMA). It also stresses the importance of theatre staff being aware of the immediate post-operative problems. I thank Navneet for this excellent chapter and being part of our team.

In our chapter on type I thyroplasty, we demonstrate step-by-step, and with photographs, the way we have successfully operated in Derby for several years using custom made silicone implants. With type I medialization being the most commonly performed laryngeal framework surgery procedure across the world, I feel that it is the 'bread and butter' for the specialist framework voice surgeon; rather like tonsillectomy for a general ENT surgeon. This chapter is full of clear photographs of the procedure itself and of the common pitfalls. I thank Smita

Bangad, a good friend and colleague, for her input in this chapter and her help in the later years of my clinical career.

Marc Remacle and V. M. N. Prasad's chapter on type I medialization using the Montgomery Implant illustrates this technique in detail with brilliant text and photographs. Typically of Marc, it is very informative and explains his practice of measuring the 'Direct Peak Subglottic Pressure' (DPSGP) intra-operatively using a trans-cricothyroid catheter, which indicates the lowest subglottic pressure necessary for voicing, e.g. the lower the DPSGP, the better the voice. They also illustrate the GA technique, mentioning their preference of LMA to size 6 ET tube and the assessment of glottis closure checked with a flexi scope passed through a port in the connecting tube of the LMA.

Reflecting the wealth of experience and communication skills of the authors, Nupur Kapoor Nerurkar and Jayakumar Menon, the chapter on arytenoid adduction describes a technically challenging operation in a comprehensive way, yet which can be easily understood by beginners in voice surgery. The authors are good friends of ours and always supported our work in India.

We are extremely thankful to Mark Watson and Jane Shaw for their chapter on injection laryngoplasty. Although, strictly speaking, it is not a framework surgery, our book would have been incomplete without this contribution.

Simon Carney and Theodore Athanasiadis's chapter on type II thyroplasty very nicely describes cordectomy (Dennis & Kashima), cordotomy, and other lateralization procedures. Simon mentions the importance of enlarging the airway, while trying to avoid a major impact on vocal function. The authors review various surgical options, including cordectomy/cordotomy, arytenoidectomy, arytenoid abduction, suture lateralization, re-innervation, laryngeal pacing, and Botox injection. Simon wonders why the term 'foldotomy' is not used instead of cordotomy and we often wondered the same! I like Simon's optimism in relation to re-innervation techniques and I hope it comes true. We thank Simon, a former Derby trainee, for contributing this chapter in spite of his busy schedule in Australia.

Marc Remacle and V.M.N. Prasad describe type III thyroplasty – relaxing with a midline wedge. This procedure lowers the vocal pitch and is mainly performed for female to male transsexual patients and mutational falsetto (puberphonia) in males who do not respond to voice, or psychotherapy.

Chapters on cricothyroid approximation by Meredydd Harris and Declan Costello and laryngeal resizing by James P. Thomas describe feminization of

voice by two different techniques. Cricothyroid approximation (CTA) describes transgender voice feminization and its occasional indication for androphonia. This chapter stresses the importance undertaking speech therapy for transgender patients in a specialized centre.

Laryngeal resizing by James P. Thomas illustrates this complex technique with excellent photographs, as we have come to expect from a laryngologist whom, I recall, gave a presentation on 'How to get good images of the larynx' in one of our British Voice Association educational meetings.

Vocal fold augmentation in children by Deepak Mehta and Prasad Thottam describes the paediatric larynx, which is still growing, and the differences in anatomy from the adult larynx. Based on their experience in the USA, they are of the opinion that temporary injection medialization is preferred to framework surgery. Specifically, their chapter tells you when ***not*** to undertake LFS in children. We thank Deepak, a former Derby trainee, for this chapter.

This guide ends with a chapter from Markus Hess on future techniques in phonosurgery, featuring numerous informative photographs and new ideas which are self-explanatory.

Aside from those who have contributed directly, I have to thank Professor Hans Mahieu for teaching me almost everything I learnt, allowing me to attend his clinics and operating theatre sessions at the Vrije Universiteit (VU) in Amsterdam and, more importantly, giving me the opportunity to meet and learn from the Master and the undisputed 'Father of Laryngeal Framework Surgery', Professor Nobuhiko Isshiki, during his laryngeal framework surgery courses in Amsterdam.

Special thanks go to Ragwinder (Bindy) Sahota, an ENT Speciality trainee at the Royal Derby Hospital, whose IT skills have been put to best use in tirelessly managing all images for this book.

Finally, I must thank my good friends and co-editors, Kate Young and Owen Judd, for doing all the important work during all those weekends, in spite of their busy clinical schedules and family commitments.

Sharat Mohan

SECTION I: OVERVIEW

1

Introduction and classifications

Declan Costello and Owen Judd

Introduction

A voice is vital for communication in order to work, attend education, socialize, and function at home. Voice disorders (hoarseness, voice loss or discomfort when speaking) are common in a world where 90 % of all professions require a degree of voice use. In the Western world, approximately 1 in 25 (or around 40 million) of the general population will suffer from voice difficulties at some stage of their lives. In the USA alone, the National Institute on Deafness and Other Communication Disorders (NIDCD) collated statistics and reported in 2015 that an estimated 17.9 million US adults aged 18 or older, or 7.6 % of the population, reported having had a problem with their voice in the past 12 months.

Of the estimated 40 million humans with voice problems in the West, statistically, 20 % of children have a voice problem during their early years and one out of every five teachers in the front line of voice use will suffer from poor vocal health. After teachers, the US National Center for Voice and Speech (NCVS) reports that entertainers (singers and actors), factory workers or machine operators, managers, clerical workers, and sales personnel feature highly on their list of client referrals.

Add to this the rate of growth of the aging population, which is increasing year on year. Older people without an adequate voice risk losing their ability to work successfully as retirement ages increase and, later, face social isolation as they become less mobile and rely on telecommunications to keep in touch. In all walks of life, whether social or commercial, maintaining vocal strength

during the aging process becomes further necessary in order to compensate for impaired hearing, which often also affects this population.

Disruption to vocal communication has a greater economic impact than might be expected, reflected in lost time from work and poor performance among professional voice users. The estimated cost of voice disorders to the British economy alone is approximately £200 m a year. The potential loss of work and social support produces stress and depression, which will invariably impact on general health, with further implications for individuals, care providers, companies, and national economies. These factors, among many others, have led to the clinical development and importance of voice disorders and phonosurgery worldwide over the last few centuries.

History

The first known published essay on diseases of the larynx was written by Giovanni Codronchi of Italy in 1597. However, it wasn't until three years later that a full account of the larynx as a vocal organ, *De Larynge vocis organo*, was published by Hieronymus ab Aquapendente. The first laryngoscope, or 'glottiscope', was presented to the Hunterian Society in London by Benjamin Guy Babbington in 1829. In 1855, an adaptation of this device, utilizing reflected sunlight, was presented to the Royal Society of London in a paper entitled 'Observations on the Human Voice' by Manuel Garcia. This technique sparked a great interest in the new specialty of laryngology and Garcia became regarded as the 'father' of the field. He went on to have honours bestowed upon him by other great physicians of the time, including a great celebration of his 100th birthday in 1905, which was attended by laryngologists from all over the world.

In 1859, Sir Morell MacKenzie began to master laryngoscopic techniques and established a rapidly developing laryngology practice. In 1863, he won the Jackson Prize of the Royal College of Surgeons of England with his paper, 'The Pathology and Treatment of Laryngeal Disease', and went on to publish the first great textbook of laryngology in 1865: *The Use of the Laryngoscope in Diseases of the Throat*. He was just 26 years of age and had established a reputation as the leading laryngologist in the UK. He is still regarded as one of the great pioneers in ear, nose, and throat surgery.

Vocal fold paralysis was first studied formally in Berlin in 1863, by Carl Gerhardt. He discovered that the majority of such cases were due to recurrent laryngeal nerve lesions. The mechanism of paralysis and the vocal fold positions

were later described by German physician, Ottomar Rosenbach, in 1880. His name was attributed to the Semon–Rosenbach Law, often referred to as simply 'Semon's Law', that the abductor fibres of the recurrent laryngeal nerve are affected first in palsy, with the adductor fibres being initially spared.

Surgical treatment to restore the function of a paralysed vocal fold was not initially thought possible; however, in 1939, the first successful operative procedure was performed by Brian King in Seattle, USA. He proceeded to publish his work on the subject. Subsequently, various techniques for safe surgery on the skeleton, or framework, of the larynx were developed.

Originally described by Payr in 1915, the term 'laryngeal framework surgery' (LFS) refers to surgical procedures performed on the laryngeal skeleton, comprising the thyroid, cricoid and arytenoid cartilages, with the aim of altering the position and/or the tension of the vocal folds. From a functional point of view, LFS may serve to alter the vibratory movements of the vocal folds in such a way as to reduce glottal insufficiency (thus to reduce breathiness), or to change the pitch of voice.

However, in the pre-antibiotic era, complications were common and the concept was largely abandoned. Over the following decades, the surgical techniques were modified and evolved and, in 1974, Nobuhiko Isshiki of Kyoto University, Japan, described 'Thyroplasty as a new phonosurgical technique'. This seminal research, performed in the canine model, outlined the four types of LFS, below, that we currently recognize. Thus, Isshiki can be seen as the 'father' of modern laryngeal framework surgery. Isshiki described the importance of surgery under local anaesthesia in order to obtain constant vocal feedback from the patient. He went on to develop the now widely used Isshiki Classification for Laryngeal Framework Surgery.

Classifications

Isshiki described four basic surgical procedures that he called thyroplasty types I–IV. He also described arytenoid adduction, which aims to close the posterior glottis. The four types were

- thyroplasty type I (medialization)
- thyroplasty type II (lateralization)
- thyroplasty type III (relaxing)
- thyroplasty type IV (tensing).

In 2001, the Phonsurgery Commitee of the European Laryngological Society (ELS) produced a classification and nomenclature system that incorporated Isshiki's own descriptions from 1974, and added further procedures that had been developed in the intervening years:

- Approximation laryngoplasty
  - Medialization thyroplasty
    - (Thyroplasty type I)
  - Arytenoid adduction
    - *Rotation (pull) techniques*
      - (Lateral cricoarytenoid pull technique)
    - *Fixation techniques*
      - (Adduction arytenopexy)

- Expansion laryngoplasty
  - Lateralistion thyroplasty
    - *Lateral approach*
      - (Thyroplasty type IIa)
    - *Medial approach*
      - (Thyroplasty type IIb, expansion of the anterior commissure, midline lateralization thyroplasty)
  - Vocal fold abduction
    - Suture technique
    - Resection technique
    - (Thyroarytenoid myectomy)

- Relaxation laryngoplasty
  - Shortening thyroplasty
    - *Lateral approach*
      - (Thyroplasty type III)
    - *Medial approach*
      - (Anterior commissure retrusion)

- Tensioning laryngoplasty
  Cricothyroid approximation
    (Thyroplasty type IVa, cricothyroid subluxation)
  Elongation thyroplasty
    Lateral approach
      (Thyroplasty type IVb)
    Medial approach
      (Springboard advancement, anterior commissure advancement, anterior commissure laryngoplasty)

LFS has been applied in numerous different circumstances, with the most commonly performed procedure being a type I thyroplasty, primarily an operation for glottal insufficiency, that aims to maximize glottal closure during phonation, cough, and swallow.

Prior to discussion of the nuances of LFS, it is necessary to have a precise and detailed understanding of laryngeal anatomy and physiology as described in the next chapter.

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2

Anatomy and physiology of the larynx

Owen Judd and Declan Costello

Anatomy

The larynx is composed of three elements: the skeleton, the mucosal layer, and the muscles.

The laryngeal skeleton

The skeleton of the larynx is composed of a single bone, the hyoid, and nine cartilages. There are three unpaired cartilages: the thyroid, cricoid, and epiglottic; and three paired: the arytenoid, corniculate, and cuneiform.

The hyoid

The hyoid bone (Figure. 2.1) suspends the cartilaginous skeleton of the larynx and is itself suspended from the skull by the suprahyoid muscles. The function of the hyoid is to elevate and lower the larynx during phonation and changes in pitch. It consists of a central body and two pairs of horns, or cornu – the lesser and greater – and is connected to the thyroid cartilage by the thyrohyoid muscles, membrane, and ligaments.

The thyroid cartilage

The thyroid cartilage (Figure. 2.2) makes up the greatest part of the laryngeal skeleton. It comprises two flat plates of hyaline cartilage which meet in the midline and form the laryngeal prominence. Superiorly in the midline there is a depression, named the superior thyroid notch, and a corresponding inferior

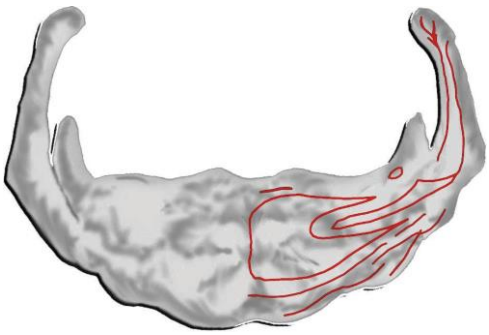

Figure. 2.1: Hyoid showing muscle attachments, seen from above. Author image.

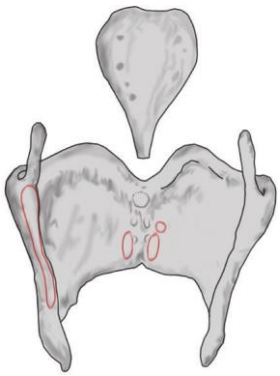

Figure. 2.2: Muscle attachments on thyroid cartilage and epiglottis, seen from the rear. Author image.

thyroid notch at its lower border. Posteriorly, there are superior and inferior thyroid horns, or cornu. The superior cornu takes attachment of the thyrohyoid ligament. The inferior cornu articulates with the cricoid cartilage, as do the posterior lower edges of the thyroid cartilage, to form the cricothyroid joints. These synovial joints move with action of the cricothyroid muscle. The whole superior border of the thyroid cartilage is suspended from the hyoid bone by the thyrohyoid membrane. The thryohyoid muscle is attached along the oblique line of the laminae.

The cricoid cartilage

This ring of hyaline cartilage is shaped as a 'signet ring' with the narrow section anteriorly placed and a broader lamina posteriorly. It is the only complete ring of cartilage in the airway. The cricoid (Figure. 2.3) is positioned immediately inferior to the thyroid cartilage and is attached to it anteriorly by the cricothyroid ligament and membrane and articulates directly with the thyroid cartilage posteriorly at the cricothyroid joint. The cricothyroid muscle originates from this cartilage anterolaterally and fans outwards and upwards to attach to the lower border and inferior

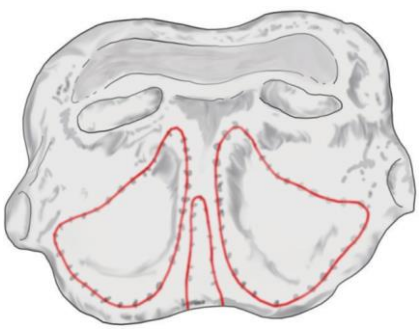

Figure. 2.3: Cricoid cartilage. Author image.

cornu of the thyroid cartilage. The cricoid cartilage is also the origin of posterior cricoarytenoid and lateral cricoarytenoid muscles. The posterior superior border of the cricoid cartilage is the articular surface for the arytenoid cartilages.

The epiglottic cartilage

This is a leaf-shaped extension of elastic cartilage attached to the internal laminae of the thyroid cartilage in the midline. During swallowing, as the hyoid elevates the larynx, the epiglottis flattens and closes over the laryngeal inlet to provide protection against aspiration.

The arytenoid cartilages

These paired cartilages (Figure 2.4) are the main functioning elements of voice production and vocal fold movement. They dictate the position and tension of the vocal folds. The arytenoids are pyramid-shaped structures of hyaline cartilage which articulate from their base as a synovial joint with the posterolateral surface of the cricoid. They have three surfaces: the posterior surface and lateral border provide origin of the oblique and transverse interarytenoid muscles which traverse the posterior larynx to attach to the other arytenoid cartilage. On the anterolateral surface of the cartilage is a ridge which curves downwards and anteriorly to form a medial process. This is termed the 'vocal process' and gives attachment to the vocal ligament, a band of yellow elastic tissue which spans the glottis and attaches into the midpoint of the posterior midline of the thyroid cartilage. The anterior surface and base of the cartilages provide attachment of the thyroarytenoid muscle. The lateral angle of the base of the cartilage points backwards and laterally to form the 'muscular process'. This is where the posterior cricoarytenoid and lateral cricoarytenoid muscles attach. The apex of the arytenoid cartilages form an articulation with the corniculate cartilages.

The corniculate and cuneiform cartilages

These small elastic paired cartilage structures form the tip of the arytenoids (Figure 2.5) and most medial aspect of the aryepiglottic folds respectively. They serve to stiffen and strengthen the mucosal folds.

Mucosa of the larynx

The majority of the mucosal surface of the larynx and pharynx above the level of the vocal folds is of stratified squamous epithelial type. Below the level of the

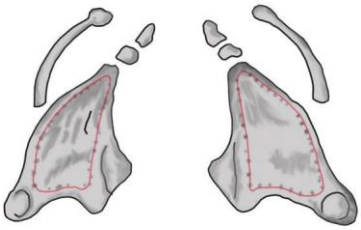

Figure 2.4: Arytenoids with corniculate and cuneiform cartilages. Author image.

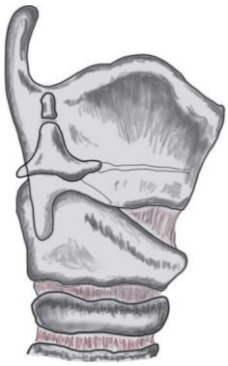

Figure 2.5: Lateral view of the laryngeal framework. Author image.

vocal folds, goblet cells are present to produce mucus and the mucosa changes to a pseudostratified ciliated columnar epithelium.

The structure of the vocal folds themselves is highly specialized and unique. They consist of five layers:

1. Epithelium – non-keratinizing stratified squamous epithelium.
2. Superficial lamina propria (Reinke's space) – loose fibrous tissue and gel matrix.
3. Intermediate lamina propria – mainly elastin fibres with some fibroblasts.
4. Deep lamina propria – mainly collagen and rich in fibroblasts.
5. Thyroarytenoid/vocalis muscle complex.

Generally speaking, the first two layers form the vibratory surface or 'cover' of the vocal fold, with the gelatinous consistency of Reinke's space allowing fluency of epithelial vibration and a free-flowing mucosal wave.

The intermediate and deep layers of the lamina propria form a transitional zone and together make up the vocal ligament. The body of the vocal fold consists mainly of the muscular layer (Figure 2.6).

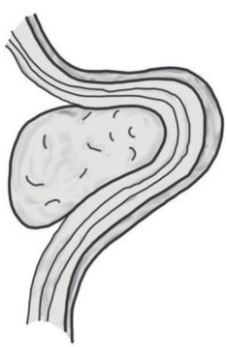

Figure 2.6: Vocal fold edge demonstrating cover, transition layer, and body of the thyroarytenoid muscle (from outwards to inwards). Author image.

The muscles

The main actions of the muscles of the larynx are: adduction (closure), abduction (opening), tensing, and shortening (Figure 2.7 and Figure 2.8).

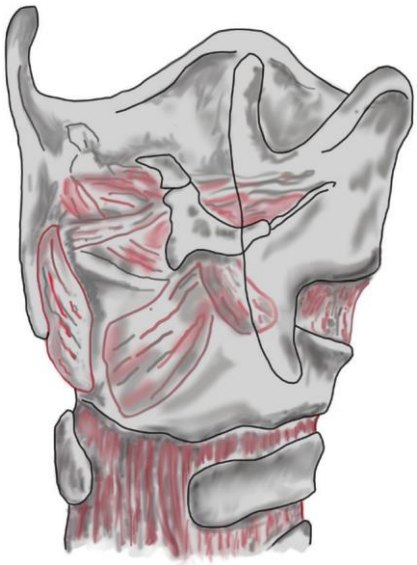

Figure 2.7: Posterolateral view of the laryngeal framework. Author image.

Adductors

Thyroarytenoid The thyroarytenoid muscle has two parts. The medial and deeper compartment is termed the vocalis muscle and lies parallel to and adherent to the vocal ligament. It forms the main part of the body of the vocal fold. The lateral compartment is termed muscularis, thyroepiglotticus or ventricularis muscle. It is attached to the edges of the epiglottis and ventricle.

Lateral cricoarytenoid This muscle is one of two which arise from the cricoid and attach into the muscular process of the arytenoid, and has an antagonistic action with the other muscle, the posterior cricoarytenoid. It is the major adductor of the vocal folds.

Interarytenoid The interarytenoid muscle comprises two separate muscle sections, the transverse and oblique arytenoid muscles. Both muscles run from one arytenoid to the other posteriorly.

Abductors

Posterior cricoarytenoid This is the only pair of muscles that abduct the vocal folds. They are also described as respiratory muscles for that reason. They are exactly antagonistic to the lateral cricoarytenoids above.

Tensors

Cricothyroid This muscle is responsible for opposing the cricoid and thyroid cartilages via backward tilt of the cricothyroid joints. The cricothyroid tenses the folds and so increases the pitch of the voice.

Thyroarytenoid Contraction of the thyroarytenoid muscle results in shortening of the vocal folds, and causes an increase in stiffness.

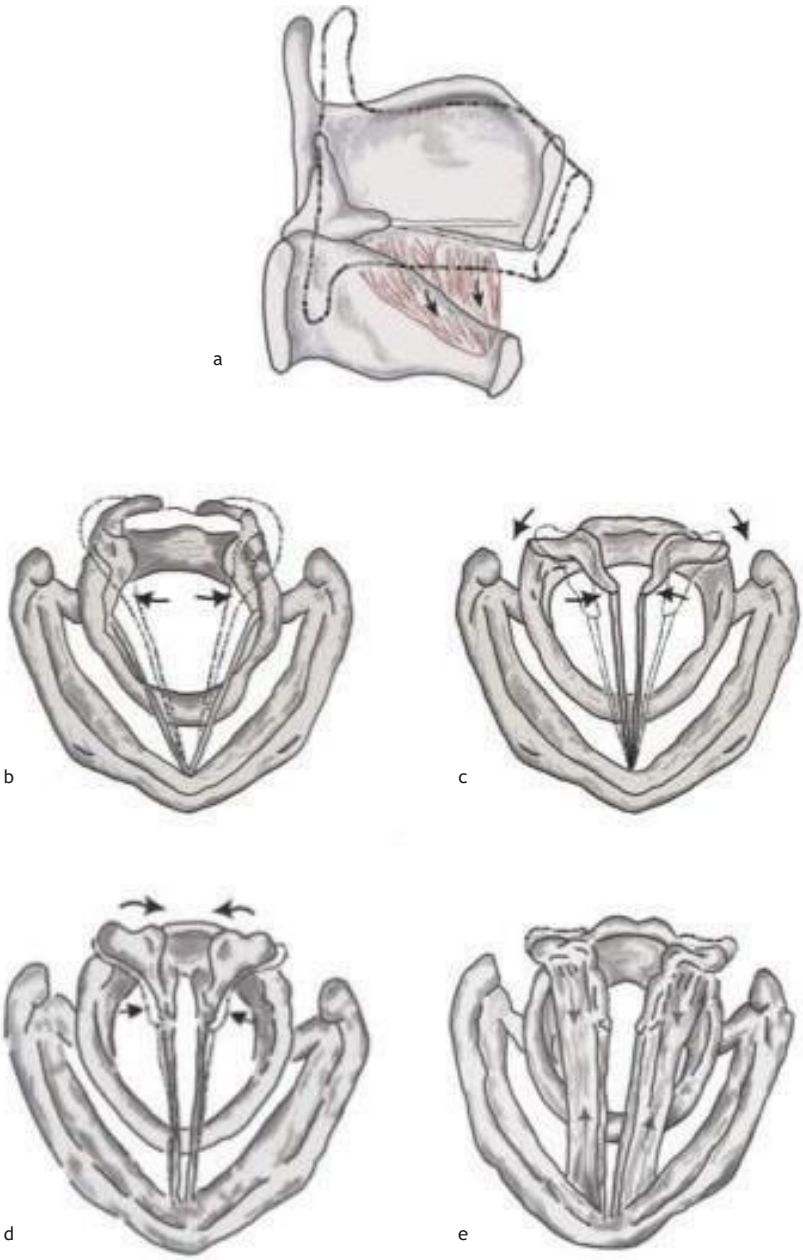

Figure 2.8: Intrinsic laryngeal muscles and their actions. Author image. **a:** Cricothyroid muscle. **b:** Posterior cricoarytenoid muscle (PCA). **c:** Lateral cricoarytenoid muscle (LCA). **d:** Interarytenoid muscle (IA). **e:** Thyroarytenoid muscle (TA).

Table 2.1: Summary of laryngeal muscles and their actions

Muscle	Origin	Insertion	Action on vocal folds	Effect on voice
Thyroarytenoid	Lower midline internal thyroid lamina	Anterior surface and base of arytenoid	Adducts, shortens, thickens, lowers, narrows laryngeal inlet Cover – slackened Body – stiffened	Enables voicing Lowers pitch Enables cough
Lateral cricoarytenoid	Lateral cricoid	Anterior surface of muscular process of arytenoid	Adducts, elongates, lowers, thins Cover – tightened Body – stiffened, edge of fold sharpened	Enables voicing Sharpens voiced sounds Whisper (when used in isolation)
Transverse interarytenoid	Lateral margin of arytenoid	Lateral margin of contra-lateral arytenoid	Adducts, medial compression of posterior glottis Cover – stabilized Body – neutral	Enables voicing Falsetto
Oblique interarytenoid	Base of arytenoid	Apex of contralateral arytenoid	Adducts, medial compression of posterior glottis, narrows laryngeal inlet Cover – neutral Body – neutral	Enables voicing Falsetto Enables cough

Muscle	Origin	Insertion	Action on vocal folds	Effect on voice
Posterior cricoarytenoid	Posterolateral face of cricoid lamina	Posterior surface of muscular process of arytenoid	Abducts, elongates, elevates, thins Cover – tightened Body – stiffened, edge of fold rounded	Disables voicing Inspiration/breathing
Cricothyroid	Anterolateral arch of cricoid	Two bellies: Oblique attaches to posterior half thyroid lamina and inferior cornu Vertical attaches to inferior border of thyroid lamina	Elongates, lowers, tenses, thins Cover – tightened Body – stiffened, edge of fold sharpened	Raises pitch

Nerve supply

The neural supply to the larynx derives from the vagus nerve, the tenth cranial nerve. The vagus gives off two main branches to the larynx, the superior laryngeal nerve (SLN), and the recurrent laryngeal nerve (RLN).

Superior laryngeal nerve

This nerve has two branches: internal and external. The internal laryngeal nerve provides sensory innervation to the mucosal surface of the larynx above the level of the vocal folds. The external laryngeal nerve supplies a single muscle – the cricothyroid. Therefore lesions of the superior laryngeal nerve present with inability to raise the pitch of the voice and coughing/choking episodes due to lack of supraglottic sensation.

Recurrent laryngeal nerve

The nerves to the left and right have different paths. The left RLN descends into the chest and hooks around the arch of the aorta to ascend back to the larynx. On the right, however, the RLN does not descend into the chest but loops around the right subclavian artery at the root of the neck. The RLN innervates all the intrinsic laryngeal muscles, except the cricothyroid, and supplies sensation from the vocal folds inferiorly. Lesions of the RLN therefore lead to vocal fold palsy.

Physiology of the laryngeal framework

Functions of the larynx

The human larynx fulfils three main functions: airway protection, respiration, and phonation. In addition, the larynx is used for coughing to expel foreign material from the airway, and for the Valsalva manoeuvre (when straining).

Protection of the airway during swallowing is achieved by closure of the true and false vocal folds, elevation of the larynx, and posterior reflection of the epiglottis to close the laryngeal inlet.

During normal quiet respiration, the vocal folds are in an abducted position, with the posterior cricoarytenoid in tonic contraction. During deep inspiration, the vocal folds abduct more widely.

Phonation and speech

The production of intelligible speech relies on a complex interaction between several different structures:

- the lungs provide an energy source;
- the vocal folds produce sound by vibrating;
- the pharynx, oral cavity and other areas modulate the resonant frequencies; and
- the mouth, soft palate and lips provide articulation.

All of these functions must be intricately coordinated for speech to be produced.

During phonation, the adductors of the vocal folds cause approximation of the arytenoid cartilages, bringing the vocal folds into close proximity. Airflow from the lungs causes vibration of the vocal folds, producing acoustic energy (sound).

The vibratory cycle of the vocal folds is described as a 'mucosal wave': pressure of air from the lungs builds under the closed vocal folds, and when the pressure exceeds the glottic closure forces, air escapes between the vocal folds. The elasticity of the vocal folds causes the vocal folds then to close again a fraction of a second later, and the vibratory cycle starts again. The closure of the vocal folds is augmented by the Bernoulli effect (in which a fluid or gas passing between two surfaces causes a negative pressure between those surfaces – in other words, the flow of air causes the side walls (the vocal folds) to tend to come together). When viewed in coronal section (Figure 2.9), the mucosal wave is seen to propagate from inferiorly to superiorly: initially, just the most inferior margins of the vocal folds move apart. The superior borders of the vocal folds

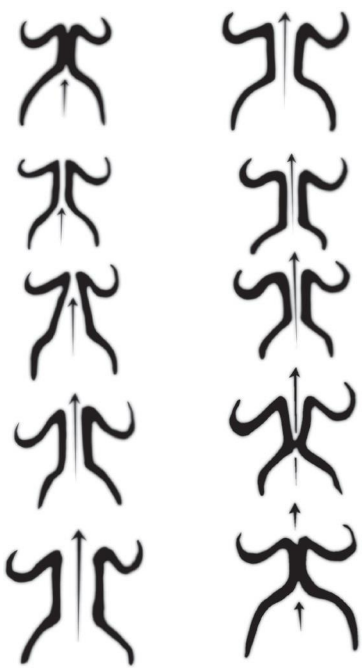

Figure 2.9: Mucosal wave pattern coronal view. Author image.

then open; the inferior surfaces then close, followed by the superior surfaces. The cycle then starts again.

The epithelial cover of the vocal folds is separated from the (relatively) stiff ligament by Reinke's space. It is this loose collagenous layer that allows the epithelium to glide over the ligament in a smooth fashion. When viewed in slow motion, this appears as a mucosal wave.

The production of a normal vocal quality relies on:

1. **Closure of the glottis**. Failure of adduction of one or both vocal folds results in poor closure and, hence, a breathy sound.
2. **Vocal folds with straight edges**. Complete closure of the glottis requires epithelial surfaces that are free from irregularities on their medial edges.
3. **A normal mucosal wave**. Any areas of the vocal fold in which there is tethering between the epithelium and the ligament will result in a non-vibratory portion of vocal fold. This results in failure vocal fold vibration that is perceived as a 'rough' quality of voice.

The pitch of voice (frequency of vibration) produced by the vocal folds is a function of:

1. **Mass per unit length**. Stretching the vocal fold results in a reduction in mass per unit length and an increase in pitch. This happens when the cricothyroid muscle contracts. Conversely, when the thyroarytenoid muscle contracts, the vocal folds shorten and increase in mass per unit length; the pitch falls.
2. **Stiffness**. Increasing the tension in the vocal fold (for example, isometric contraction, in which both thyroarytenoid and cricothyroid are working 'against' each other) alters the vibratory qualities and pitch of the vocal fold.

Different forms of laryngeal framework surgery can be employed to: increase the tension on the vocal folds, mimicking the cricothyroid muscle (as in type IV thyroplasty, cricothyroid approximation); or to medialize a paralysed vocal fold that is failing to close the glottis (as in type I thyroplasty). Equally, the vocal folds can be shortened (as in type III thyroplasty).