Laryngeal and Tracheobronchial Stenosis

Guri S. Sandhu, MD, FRCS
S. A. Reza Nouraei, MBBChir, PhD, FRCS

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Foreword

It has been more than 40 years since the publication of William Montgomery's *Surgery of the Larynx and Trachea* and extraordinary advances have been made during the intervening years. There is a significant need for a comprehensive resource such as *Laryngeal and Tracheobronchial Stenosis*, and Guri Sandhu and his protégé Reza Nouraei have completed an ambitious endeavor to put together a collaborative work on the comprehensive evaluation, management, and treatment of laryngeal and airway stenosis.

It begins as all complete works should, with a history of airway surgery, and following this we look at both anatomy and pathophysiology before embarking on the care of a wide variety of pathologic processes. It is comprehensive in nature not only discussing the sequela of tracheotomy and post-intubation injury, but also laryngeal trauma and the management of airway foreign bodies. This text also includes outstanding sections on anesthesia technique as well as practical matters such as how to put together an airway management team. Finally, it concludes with an outstanding chapter on tracheal transplantation and tissue regeneration which represents the greatest area for future advances in this field.

As a surgeon I appreciate good illustrations and photographs, and this volume is richly illustrated which helps in our understanding of how to approach and perform the surgical techniques that are described.

Indeed I have found that my clinical practice has already improved by reading this collective experience and knowledge of many colleagues across the globe, and it is my suspicion that many other readers of this outstanding textbook will reach the same conclusion.

Overall Dr. Sandhu and Dr. Nouraei should be congratulated as they have provided airway surgeons with a unique scholarly contribution to our field which is well written and referenced. It should be part of the library of all airway surgeons and available in all otolaryngology and thoracic surgery training programs.

—Gregory N. Postma, MD
Director and Vice Chairman
Department of Otolaryngology-Head and Neck Surgery
Georgia Regents University
Augusta, Georgia

CHAPTER 1

History of Airway Surgery

Jonathan Hughes

TRACHEOSTOMY AND AIRWAY INTUBATION

Tracheostomy is one of the oldest operations, with the earliest description found in the *Rig Veda*, the ancient Hindu book of medicine, at around 2000 BC.[1] Five centuries later in Egypt a technique resembling tracheostomy was first documented in written form to treat respiratory obstruction, following the work of Imhotep. Hippocrates (460–380 BC) condemned the practice of tracheostomy due to the risk of carotid artery injury and was the first to describe intubation of the trachea to support ventilation.[2] Alexander the Great (356–323 BC) reportedly used his sword to cut open the trachea of a soldier suffering from an aspirated bone.

It appears from the historical record that at around 100 BC, tracheostomy was being performed more often, with descriptions by Aesculapius, Aretaeus, and Galen in the second and third centuries. Fabricius of Aquapendente introduced the idea of a tracheostomy tube. However references to the procedure subsequently disappeared until the height of the Renaissance with the work of the Flemish anatomist Andreas Vesalius (AD 1514–1564): *De Humani Corporis Fabrica*.[1] In 1543 Vesalius reported the first tracheal intubation in an animal. The first recorded successful tracheostomy was for treatment of a pharyngeal abscess by the Italian physician Antonio Musa Brasavola in 1546.[3] Marco Aurelio Severino used tracheostomy during an epidemic of diphtheria in Napoli in 1610, using the vertical incision recommended by Fabricius. Tracheostomy tubes and straps were illustrated in 17th-century surgical texts, and the first use of the word *tracheotomy* was made by the Belgian Thomas Fienus in 1649. The German Lorenz Heister in 1718 was the first to use the term *tracheostomy*. George Martin in 1732 described the use of an inner cannula with a tracheostomy tube. The first references are made to endotracheal intubation in the context of resuscitation in 1754 by the English obstetrician Benjamin Pugh in neonates.[4] It was later described for the resuscitation of drowning victims, reflecting the medical cases of the time. As understanding of the therapeutic value of tracheostomy and tracheal intubation continued, perhaps the most famous case of a failure to perform the procedure occurred in 1799, with the death of the first president of the United States, George Washington, from epiglottitis. The modern concept of timely tracheostomy to obviate acute airway obstruction was pioneered by Frenchman Armand Trousseau in 1833, saving 200 diphtheria victims.[5]

During this time of tracheostomy development, experimentation with inhalational general anesthesia culminated in the publication of the first public demonstration of this technique using ether in 1846 by William Morton at Massachusetts General Hospital.[6] In 1871 the German Friedrich Trendelenburg performed the first general anesthetic using a cuffed tracheostomy tube.[7]

Edinburgh surgeon William MacEwen in 1878 was the first to perform tracheal intubation via an orotracheal route prior to surgery to resect an oral tumor. Seven years later, the American Joseph O'Dwyer developed a metal orotracheal tube that he used in patients with diphtheria and laryngeal stenosis secondary to syphilis and burns.[8] In 1888

O'Dwyer's tube was used in conjunction with an artificial ventilator in patients undergoing thoracic surgery.[7] Franz Kuhn, a German surgeon, developed metal orotracheal tubes and a curved introducer to assist their insertion.[8] Furthermore, he was the first to describe nasal intubation, as well as the importance of laryngeal topical anesthesia to prevent instrumentation-induced laryngospasm, leading the way to awake fiberoptic intubation.[8] Americans Ralph Waters and Arthur Guedel later developed the cuffed endotracheal tube, leaving the materials used to make endotracheal tubes and adjuncts to assist in their insertion, such as forceps, laryngoscopes, and fiberoptic airway endoscopy, the only remaining developments of nonsurgical airway management.

Chevalier Jackson, in 1909, completed the evolution of the technique of surgical tracheostomy, with the first modern description of the procedure, advocating a lower tracheal incision in reducing postoperative airway stenosis.[9] Figure 1–1 provides details of significant historical events in airway surgery from antiquity to the beginning of the 20th century.

LARYNGOSCOPY

The appearance and functioning of the larynx in living subjects was a mystery before the 1800s, with laryngeal structures only appreciated at autopsy. Diseases of the airway were usually infectious in origin, including syphilis, diphtheria, and tuberculosis. Diagnosis of the cause of airway obstruction and understanding of the natural history of these conditions made no progress until the description of indirect laryngoscopy in 1855 by the Spanish voice teacher, Manuel Garcia. That year Garcia presented his technique to the Royal Society of London, which relied on an angled mirror held in the subject's mouth and a second head-mounted mirror to reflect sunlight for illumination.[10] As such, Garcia has been widely cited as the first to visualize the living human larynx; however, there are earlier references of techniques to achieve this. In 1743 the French accoucheur Leveret devised an angled mirror for examining the larynx, and even a snare for removing laryngeal polyps.[10] The German Philipp Bozzini in 1807 developed an instrument called a "Lichtleiter" or "light conductor" for inspecting various anatomical openings including the mouth and larynx.[10] This primitive device is regarded as the beginning of the development of the modern endoscope. Again pre-dating Garcia, Englishman Benjamin Babington exhibited to the Hunterian Society of London in 1829 an instrument he called a "glottiscope" to examine the larynx, which was a combination of a tongue retractor and laryngeal mirror.[10,11]

Johann Czermak, Professor of Physiology at the University of Pest, first successfully used Garcia's mirrors in examining patients in 1857; earlier that year, Ludwig Turck, Professor of Laryngology in Vienna, failed in his attempts.[10] It is suggested that Czermak's success may have been related to the source of illumination; with Czermak inventing the use of magnified candlelight with a concave head mirror, rather than Turck's dependence on less reliable sunlight (Figure 1–2). In 1858, Czermak presented his work to the Vienna Imperial Society of Medicine, and indirect laryngoscopy became an increasingly popular technique in the last decades of the 19th century. Surgical instruments were subsequently developed which allowed the laryngologist to cut, cauterize, and remove laryngeal tissue with indirect visualization. However, the issues of poor illumination remained until the invention of the electric lightbulb. Moreover, advances in anesthesia would allow direct laryngoscopy and precise laryngeal surgery.

In 1852 the American Horace Green presented his experiences of using a blade-like instrument in conjunction with curved forceps to excise laryngeal lesions. However, his reports were not accepted by the medical community. Adalbert Tobold, a German laryngologist, was the first physician to directly visualize the larynx in 1864.[12] His patient was able to suppress her gag reflex to such an extent that he was able to use a tongue depressor and directly visualize her laryngeal papillomatosis. Other sources point to another German, Alfred Kirstein, in the 1890s and his adaptation of a tubed esophagoscope, he called an "autoscope."[13] Kirstein also pioneered the use of an electrical light source at the proximal end of the laryngoscope, with the light reflected down the scope with a 90° prism.

Another German, Gustav Killian, first performed suspension laryngoscopy in 1909 on a cadaver.[10]

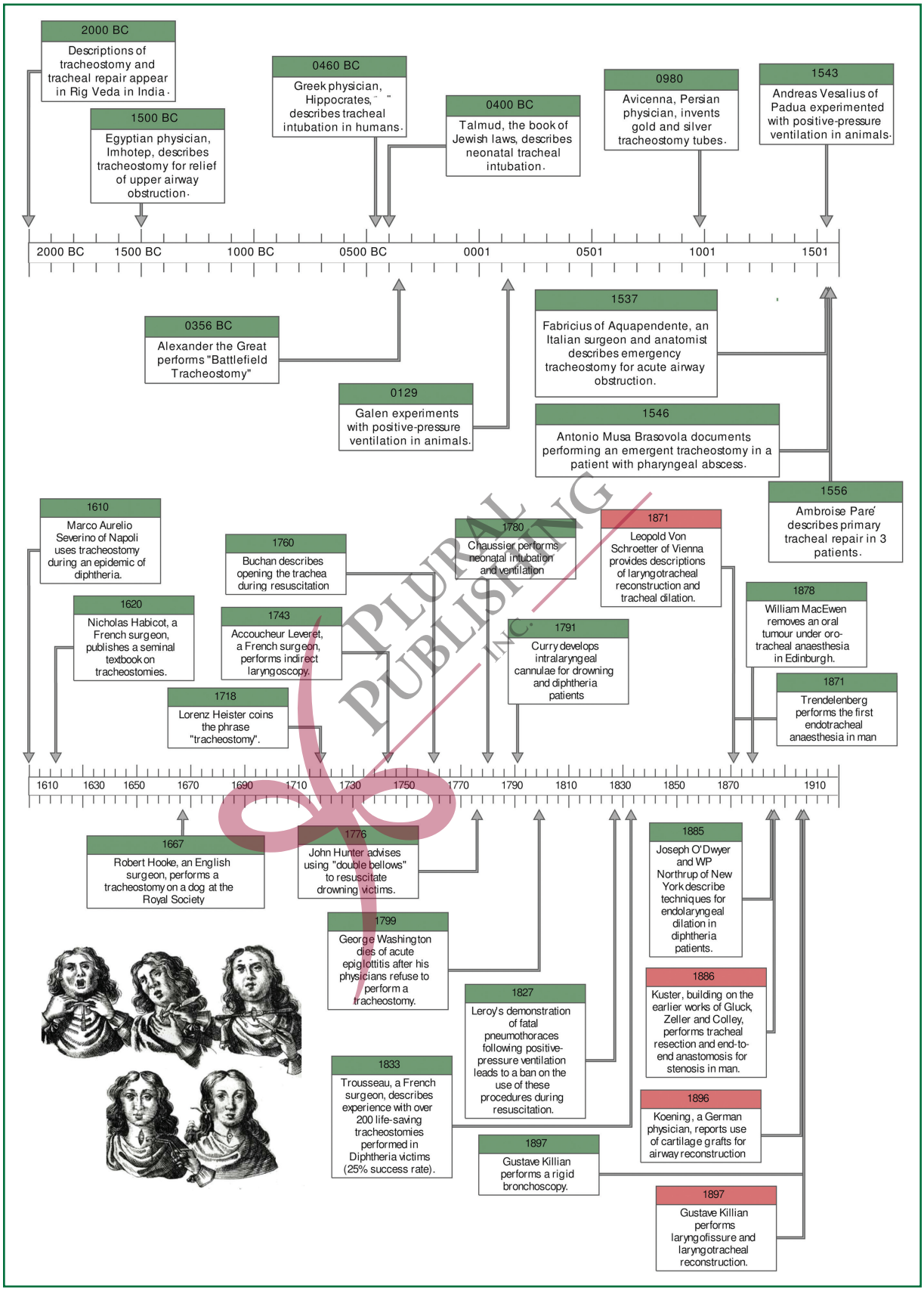

Figure 1–1. Significant historical events in airway surgery.

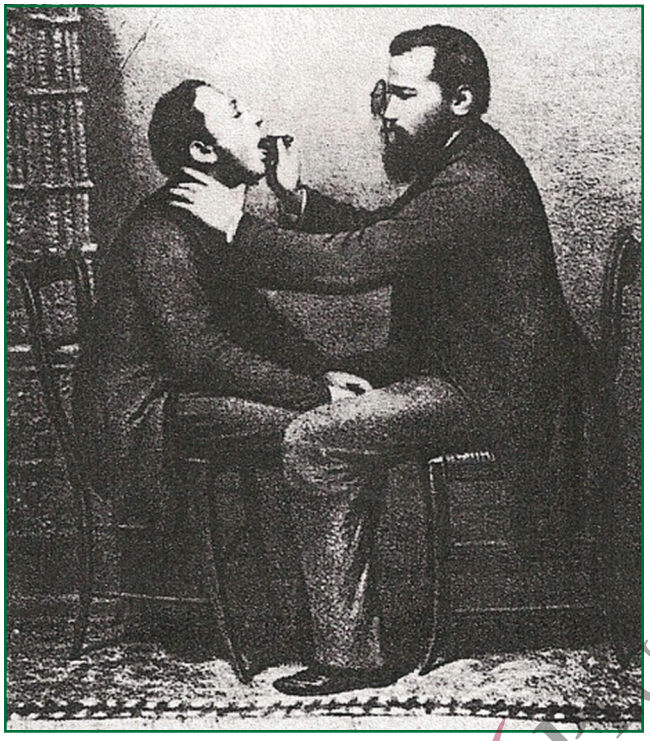

Figure 1–2. Johann Czermak performing indirect laryngoscopy.

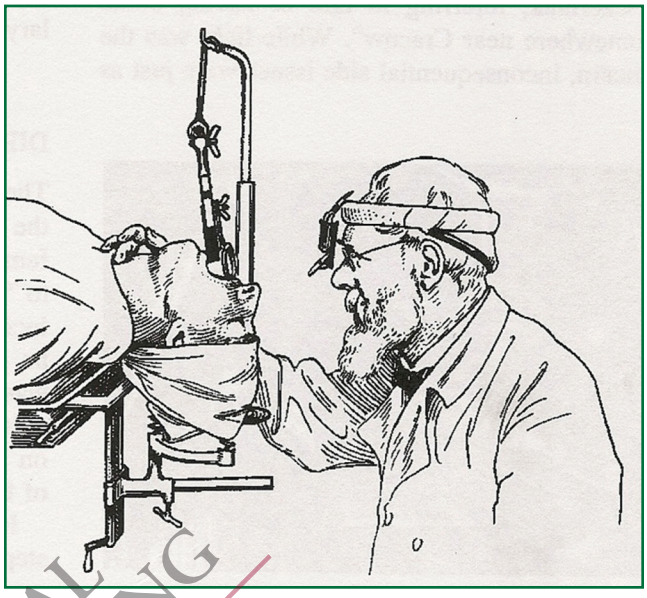

Figure 1–3. Gustav Killian performing suspension direct laryngoscopy.

He used a blade-like laryngoscope to visualize the larynx in supine subjects, attached with metal rods to the dissecting table (Figure 1–3). The apparatus became increasing complex, with development of adjustable "gallows." The great advantage of Killian's invention was that both of the surgeon's hands were able to instrument the larynx, compared to prior techniques that required one of the surgeon's hands to hold the laryngoscope. In addition to his contributions to laryngoscopy, Killian is considered the father of bronchoscopy and used a modified esophagoscope to examine the human airway.[14] In 1897 he removed a bone splinter from the right main bronchus of a farmer using an esophagoscope, forceps, and a head mirror as a light source.[15] Chevalier Jackson in 1904 made further advances in the design of the bronchoscope with a small lightbulb at the distal end and suctioning for the removal of foreign bodies from the airway.

The suspension apparatus was further developed by Robert Lewy to be used in conjunction with tubular laryngoscopes.[16] He also defined the optimal positioning of the patient during suspension laryngoscopy: atlanto-occipital extension and neck flexion—the "sniffing the morning air" position.

These advances combined with Chevalier Jackson's proposition of distal illumination, instead of Kirstein's and Killian's proximal illumination techniques, brought suspension laryngoscopy to the modern-day procedure we all recognize, frequently in combination with operating microscopes and endoscopes. Jackson originally described small bulbs placed at the end of a second much smaller tube fitted inside the endoscope lumen.[17] As fiberoptic technology advanced, reliable and intense distal illumination was achieved with metal light carriers from halogen and xenon sources.

In addition to the operating microscope, the rod-lens optical system developed in the 1950s by the Englishman Harold Hopkins has had a dramatic effect on the illumination and image quality achieved through laryngoscopy. "The Hopkins Rod" consists of a series of rod lenses, around a millimeter in length, surrounded by thousands of glass fibers to deliver illumination, that transfer the image from

the tip of the device to the surgeon's eye. Hopkins' initial invention was developed further and commercialized by Karl Storz allowing the birth of keyhole surgery.[18]

Following Killian's and Jackson's earlier work, bronchoscopy and the field of pulmonary medicine were changed forever when Professor Shigeto Ikeda presented the flexible bronchoscope in 1966.[19] Flexible laryngoscopy was introduced by Sawashima and Hirose in 1968.[20] Clinical trials demonstrated that this technique was easy to perform and teach, and well tolerated by patients.[21] Further development took place in the 1980s with distally placed computer chip cameras, eliminating fiberoptic image transmission and thereby improving image resolution.

SURGERY FOR LARYNGOTRACHEAL STENOSIS

Tracheal Resection and End-to-End Anastomosis

The *Rig Veda* noted that the trachea could re-unite "when the cervical cartilages are cut across, provided they are not entirely severed." However, Hippocrates and Aretaeus wrote that the cartilaginous nature of the trachea meant that it was difficult to heal or unite.[22,23] Ambroise Paré described suturing of trachea lacerations in stab injury patients in the 1500s.[24]

The earliest description of surgery for laryngotracheal stenosis was made by Leopold von Schroetter in Vienna in 1871, using hard rubber bougies delivered through the mouth to dilate the airway.[25,26] In 1885, Joseph O'Dwyer in New York described similar techniques of dilatation that became used widely in the United States.[27] Gluck and Zeller in 1881 demonstrated the first successful reconstructive procedure with end-to-end tracheal anastomosis in dogs, and believed that the technique could be applied in man.[28] Elliptical and bayonet anastomoses following tracheal resection in dogs were described by Colley in 1895 to prevent stenosis.[29]

The first human tracheal anastomosis after limited resection for posttraumatic stenosis was performed by Kuster in 1886.[30] Nowakowski in 1909 described complex methods of repair of cervical tracheal defects using skin or fascia lata; and through cadaveric studies placed the limit of tracheal resection at 3–4 cm.[31] Eiselsberg successfully resected 1.5 cm of trachea in a patient.[32] It was half a century later that further attempts at tracheal reconstruction were described, initially with complex staged repairs using tracheal replacement techniques. Crafoord and Eindgren recorded the use of cutaneous reconstruction in 1945.[33] Belsey used wire-supported fascia, while Clagett and others used polyethylene tubes/patches to repair tracheal defects.[34,35] It was Conley in 1953 who successfully resected the second and third tracheal rings with primary end-to-end anastomosis.[36] A three-ring segment was resected for cylindroma in 1954 by Macmanus and McCormick, with end-to-end repair.[37] Incomplete lateral anastomoses were repaired with fascia lata and covering tracheostomies. Forster and Mattes in 1958 performed a series of tracheal resections reaching a 4-cm resection length via a transcervical and transthoracic approach, respectively.[38]

Grillo in 1964 reported findings from cadaveric studies into the maximum extent of tracheal resection at different tracheal levels, anastomotic tension, and mobilization techniques to increase resection length, including division of the right pulmonary ligament, freeing of the pulmonary vessels from pericardium, and separation of the left main bronchus.[39] Mulliken and Grillo reported further cadaveric research using combined cervical and mediastinal mobilization techniques in 1968.[40] They concluded that 4.5 cm could be resected with safe anastomotic tension with neck flexion and cervical release techniques; increasing to 5.9 cm with mediastinal mobilization.

Procedures to further mobilize the larynx and trachea to allow larger tracheal resections were developed by Ogura, who suggested dividing the hyoid muscles to allow closure following resection for subglottic stenosis.[41] Dedo and Fishman described thyrohyoid laryngeal release for tracheal resection.[42] Montgomery reported a so-called suprahyoid release with division of the muscular attachments of the superior surface of the hyoid and stylohyoid muscles.[43] It was believed that suprahyoid release resulted in shorter and less severe swallowing problems compared to thyrohyoid release.[44] Furthermore,