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From Thoracic Surgery to Interventional Pulmonology

A Clinical Guide

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Editors
J. Francis Turner, Jr.
Director of Interventional Pulmonology
Director of Pulmonary Rehabilitation
Pulmonary & Critical Care Medicine
Wyoming Medical Center
Casper, Wyoming
USA

Kazuhiro Yasufuku
Division of Thoracic Surgery
University of Toronto
Toronto, ON
Canada

Prasoon Jain
Pulmonary and Critical Care
Louis A Johnson VA Medical Center
Clarksburg, WV
USA

Atul C. Mehta
Buoncore Family Endowed Chair in Lung
Transplantation, Respiratory Institute
Cleveland Clinic
Cleveland, OH
USA

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We humbly dedicate this book to Professor Dr. Ko-Pen Wang. A pioneer in the art and science of Bronchoscopy and Interventional Pulmonology and an inspiration to us all.

Preface

We are privileged to introduce this new collaborative work in the field of interventional pulmonology.

From Thoracic Surgery to Interventional Pulmonology: A Paradigm Shift is an exciting alliance between thoracic surgery and interventional pulmonology experts that seeks to outline and discuss options available to practitioners surrounding 15 difficult topics which regularly confront interventional pulmonologists and thoracic surgeons.

As minimally invasive techniques and devices have rapidly advanced owing to technological improvements, the options for treatment of difficult airway, pleural disease, as well as staging and diagnosis of cancer have leapfrogged forward at an amazing pace.

With this advancement, we must ever serve our patients to offer the most efficacious options for their individual needs.

As such, this book offers reviews of specific questions with each chapter written with the collaboration of both an interventional pulmonologist and thoracic surgeon.

With this timely subject matter tailored to some of the most difficult questions in pulmonary medicine and thoracic surgery, we hope the readers will gain insight into the powerful collaboration available between our disciplines for the improved care of our patients.

Casper, Wyoming, USA	J. Francis Turner, Jr.
Clarksburg, WV, USA	Prasoon Jain
Toronto, ON, Canada	Kazuhiro Yasufuku
Cleveland, OH, USA	Atul C. Mehta

Contents

Contributors

Ghulam Abbas, MD, MHCM, FACS Chief, Division of Thoracic & Esophageal Surgery Professor, Dept of Cardiovascular & Thoracic Surgery Medicine, WVU Medicine, Morgantown, WV, USA

Ritesh Agarwal, MD, DM Department of Pulmonary Medicine, Postgraduate Institute of Medical Education and Research (PGIMER), Chandigarh, India

Sameer K. Avasarala, MD Division of Allergy, Pulmonary, and Critical Care, Vanderbilt University Medical Center, Nashville, TN, USA

Jamie L. Bessich, MD Interventional Pulmonology Program, Division of Pulmonary, Sleep and Critical Care Medicine, New York University Grossman School of Medicine, New York, NY, USA

Martina Bonifazi, MD Department of Biomedical Sciences and Public Health, Università Politecnica delle Marche, Ancona, Italy

Pulmonary Diseases Unit, Azienda Ospedali Riuniti, Ancona, Italy

Robert F. Browning Jr., MD, FACP, FCCP, DAABIP Interventional Pulmonology, Pulmonary and Critical Care Medicine Service, Walter Reed National Military Medical Center, Bethesda, MD, USA

Normand R. Caron, MD, PhD Thoracic Surgery, Harry S. Truman Memorial Veterans Hospital, Columbia, MO, USA

Kasia Czarnecka-Kujawa, MD, FRCPC, MPH Division of Respirology, Toronto General Hospital, University Health Network, University of Toronto, Toronto, ON, Canada

Division of Thoracic Surgery, Toronto General Hospital, University Health Network, University of Toronto, Toronto, ON, Canada

Himanshu Deshwal, MD Division of Pulmonary, Sleep and Critical Care Medicine, New York University Grossman School of Medicine, New York, NY, USA

Sahajal Dhooria, MD, DM Department of Pulmonary Medicine, Postgraduate Institute of Medical Education and Research (PGIMER), Chandigarh, India

Rajeev Dhupar, MD, MBA, FACS University of Pittsburgh School of Medicine, Pittsburgh, PA, USA

VAPHS, Pittsburgh, PA, USA

Erik E. Folch, MD, MSc Massachusetts General Hospital, Harvard Medical School, Boston, MA, USA

J. Francis Turner, Jr., MD, FACP, FCCP, FCCM, ATSF Director of Interventional Pulmonology, Director of Pulmonary Rehabilitation, Pulmonary & Critical Care Medicine, Wyoming Medical Center, Casper, Wyoming, USA

Stefano Gasparini, MD Department of Biomedical Sciences and Public Health, Università Politecnica delle Marche, Ancona, Italy

Pulmonary Diseases Unit, Azienda Ospedali Riuniti, Ancona, Italy

Erin A. Gillaspie, MD, MPH Department of Thoracic Surgery, Vanderbilt University Medical Center, Nashville, TN, USA

Rajiv Goyal, MD, MRCP Department of Pulmonary Medicine, Jaipur Golden Hospital, New Delhi and Rajiv Gandhi Cancer Institute, New Delhi, India

David Griffin, MD, FACS Intermountain Medical Center, Murray, UT, USA

Sarah Hadique, MD, FCCP Department of Pulmonary and Critical Care, West Virginia University, Morgantown, WV, USA

Associate Professor, Department of Pulmonary and Critical Care, West Virginia University, Morgantown, WV, USA

Bethany Hampole, MD Department of Thoracic and Cardiovascular Surgery, Loyola University Health System, Maywood, IL, USA

Prasoon Jain, MD, FCCP Pulmonary and Critical Care, Louis A Johnson VA Medical Center, Clarksburg, WV, USA

Jeremy C. Johnson, DO Pulmonary and Critical Care Medicine, Harry S. Truman Memorial Veterans Hospital and University of Missouri, Columbia, MO, USA

Satish Kalanjeri, MD, FCCP, MRCP Pulmonary and Critical Care Medicine, Harry S. Truman Memorial Veterans Hospital and University of Missouri, Columbia, MO, USA

Samuel V. Kemp, MD(Res), MBBS, MRCP National Heart & Lung Institute, Imperial College, London, UK

Nottingham City Hospital, Nottingham, UK

Amie J. Kent, MD Department of Cardiothoracic Surgery, New York University Grossman School of Medicine, New York, NY, USA

Sandeep Khandhar, MD, FACS Virginia Cancer Specialists USON, Inova Fairfax, University of Virginia, Fairfax, VA, USA

Danai Khemasuwan, MD, MBA, FCCP Virginia Commonwealth University Medical Center, Richmond, VA, USA

Hyun S. Kim, MD Massachusetts General Hospital, Harvard Medical School, Boston, MA, USA

Pyng Lee, MD, FCCP, FRCP, PhD Division of Respiratory and Critical Care Medicine, Department of Medicine, National University Hospital, Singapore

Yong Loo Lin Medical School, National University of Singapore, Singapore

Amit K. Mahajan, MD, FCCP, DAABIP Department of Surgery, Inova Schar Cancer Institute, Inova Fairfax Hospital, Falls Church, VA, USA

Fabien Maldonado, MD, FCCP Division of Allergy, Pulmonary, and Critical Care, Vanderbilt University Medical Center, Nashville, TN, USA

Sean McKay, MD, FACP, FCCP, DAABIP Interventional Pulmonology, Pulmonary and Critical Care Medicine Service, Walter Reed National Military Medical Center, Bethesda, MD, USA

Atul C. Mehta, MD, FACP, FCCP Buoncore Family Endowed Chair in Lung Transplantation, Respiratory Institute, Cleveland Clinic, Cleveland, OH, USA

Matthew Middendorf, MD Interventional Pulmonology, Pulmonary and Critical Care Medicine Service, Walter Reed National Military Medical Center, Bethesda, MD, USA

Philip Mullenix, MD, FACS, FCCP Department of Cardiothoracic Surgery, Walter Reed National Military Medical Center, Bethesda, MD, USA

Catherine L. Oberg, MD David Geffen School of Medicine at the University of California in Los Angeles, Los Angeles, CA, USA

Priya P. Patel, MD Department of Surgery, Inova Schar Cancer Institute, Inova Fairfax Hospital, Falls Church, VA, USA

Samaan Rafeq, MD Interventional Pulmonology Program, Division of Pulmonary, Sleep and Critical Care Medicine, New York University Grossman School of Medicine, New York, NY, USA

Armando Sabbatini Thoracic Surgery Unit, Azienda Ospedali Riuniti, Ancona, Italy

Inderpaul Singh Sehgal, MD, DM Department of Pulmonary Medicine, Postgraduate Institute of Medical Education and Research (PGIMER), Chandigarh, India

Pallav L. Shah, MD, MBBS, FRCP Royal Brompton Hospital, London, UK

National Heart & Lung Institute, Imperial College, London, UK

Chelsea and Westminster Hospital NHS Foundation Trust, London, UK

Ankur Sinha, MD Division of Pulmonary and Critical Care Medicine, Maimonides Medical Center, Brooklyn, NY, USA

Maher Tabba, MD, MS, FCCP, FACP Division of Pulmonary and Critical Care and Sleep Medicine, Tufts Medical Center, Boston, MA, USA

Wickii T. Vigneswaran, MD, MBA, FACS Department of Thoracic and Cardiovascular Surgery, Loyola University Health System, Maywood, IL, USA

Tatiana Weinstein, MD Division of Pulmonary, Sleep and Critical Care Medicine, New York University Grossman School of Medicine, New York, NY, USA

Kazuhiro Yasufuku, MD, PhD, FRCSC Division of Thoracic Surgery, Toronto General Hospital, University Health Network, University of Toronto, Toronto, ON, Canada

Chapter 1
Rigid Versus Flexible Bronchoscopy

Sameer K. Avasarala, Erin A. Gillaspie, and Fabien Maldonado

History

Rigid Bronchoscope

Professor Gustav Killian at the Poliklinik of Freiburg University (Germany) is credited with performing the first therapeutic rigid bronchoscopy on March 30, 1897 [1]. An animal bone was extracted from the right bronchus of a 63-year-old farmer [2]. A Mikulicz-Rosenheim rigid esophagoscope with rigid forceps was used for the procedure [1]. It was not the first rigid bronchoscopy Professor Killian had performed, but it was the first with a therapeutic intent [3, 4]. Chevalier Jackson was the first to perform rigid bronchoscopy in the United States [2]. He is widely regarded as an innovator in the field of otorhinolaryngology. It is reported that his clinical practice leads to a decline in the mortality rate of airway foreign body from 98% to 2% [5].

The advent of the flexible bronchoscope (FB) in the 1960s leads to a profound decline in the use of the rigid bronchoscope (RB). The development of the FB is regarded as disruptive technology; the ongoing utility of the RB came into question [6]. However, due to technological advances, the use of the RB saw a resurgence in the late twentieth century. Edwin Boyles is credited with developing the optical telescope with forward and angle viewing. Other key landmarks in the history of rigid bronchoscopy include the use of the carbon dioxide laser by Laforet (1976), the application of neodymium-doped yttrium aluminum garnet

S. K. Avasarala (✉) · F. Maldonado
Division of Allergy, Pulmonary, and Critical Care, Vanderbilt University Medical Center, Nashville, TN, USA

E. A. Gillaspie
Department of Thoracic Surgery, Vanderbilt University Medical Center, Nashville, TN, USA

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(Nd:YAG) laser by Toty (1981), and endobronchial electrosurgery being performed by Hooper Jackson (1985) [6, 7]. The initial report by Toty et al. described the use of Nd:YAG to treat 164 patients with benign or malignant central airway obstruction [7]. The refinement of the laser photo resection is credited to Jean-François Dumon, who is widely considered the father of interventional pulmonology [8]. In 1990, Jean-François Dumon published his landmark case series (188 prosthesis, 66 patients) which reported the use of the dedicated, silicone tracheobronchial stent [9].

Flexible Bronchoscope

The prototype device now known as the FB was developed in 1964; its creation is credited to Shigeto Ikeda [1]. The initial iteration of a usable instrument contained over 15,000 glass fibers. Later, the Machida bronchoscope incorporated a working channel; it was used to obtain bronchoscopic biopsies using a flexible forceps [10]. The FB continued to undergo refinement, evolving into the ubiquitous device that we currently use across specialties. Over the last three decades, there have been significant technological advances with the design of the FB. Improvements in lighting, image processing, and compatibility with accessories and devices allow the FB to remain an important tool for physicians and surgeons who manipulate the airways. Advancement in stent manufacturing and design has also led to a wider selection of stents that can be placed via a FB [11].

Design

The design of the RB varies significantly from the FB. In general, the FB is a more fragile, technologically advanced piece of equipment. The latest generation provides excellent visualization of the tracheobronchial tree via the use of charge-coupled device (CCD) chips.

Rigid Bronchoscope

Although a RB can be used in a variety of complex procedures, its design is unassuming. In simplicity, it is a straight metallic conduit to the airway. This tube allows airway visualization and provides a channel to pass and manipulate a variety of tools. Rigid bronchoscopes have three main components: barrel, multifunctional head, and an optic with a light source [1]. At present, a handful of companies manufacture rigid bronchoscopes and related equipment: Lymol Medical (Woburn, Massachusetts, USA), KARL STORZ Endoscopy-America (El Segundo, California, USA), Novatech (La Ciotat, France), and Richard Wolf Medical Instruments (Vernon Hills, Illinois, USA). Although made by different manufacturers, the general structure of the bronchoscope is similar.

Barrel

The barrel of a rigid bronchoscope is a hollow metal tube, with a beveled distal tip. They come in a variety of lengths and color-coded diameters. The outer diameter of rigid barrels ranges from 3 mm to 18 mm. The length of the rigid barrels ranges from 33 to 43 cm. The tracheal barrels are shorter and bronchial barrels have side ventilation ports. When the rigid barrel is engaged in a mainstem, the side ventilation ports allow for contralateral ventilation. The proximal end of the barrel connects to the multifunctional head.

Selecting the appropriate diameter of a barrel is an important consideration. It is predicated on several variables, including the indication and the patient's anatomy. Diameters that are too large may be difficult to pass through the glottis or stenotic airway. Barrels that are too narrow create challenges for adequate ventilation, constrain the use of instruments, or are not useful in dilating an airway. Smaller diameter barrels can be more easily introduced into the mainstem bronchi and bronchus intermedius. However, limitations in the internal diameter may hinder the ability to use multiple tools simultaneously.

Multifunctional Head

The multifunctional head (also referred to as a universal barrel) is an interface which allows rotation and attachment of the barrel to a variety of accessories and the ventilation system. A ventilation circuit is attached via the ventilation port; a closed or open ventilation strategy may be used. Depending on the type of RB that is used, the multifunctional head can be an independent piece which attaches to the barrel or be a unified extension of the barrel itself. There are a variety of instruments that can be introduced through the axial or lateral ports of the RB. These include grasping forceps, large biopsy forceps, suction catheters, laser fibers, or a microdebrider. Additionally, a FB can be passed through the RB to access airways that are beyond the reach of the rigid bronchoscope.

Optics and Light Source

There are several optics and light sources that can be used to illuminate a RB. Like other RB-related equipment, lighting equipment is produced by several manufacturers. The visualization system is comprised of two pieces, an optic (also referred to as a telescope) and a light source. The optic is made from a thin glass rod, which is connected to a proximal light source via fiber-optic cable.

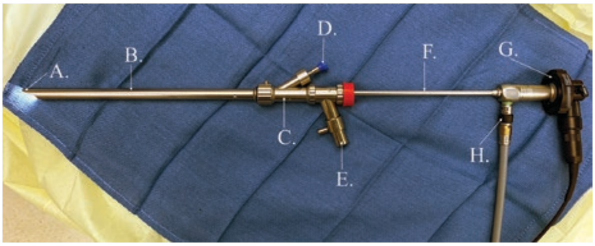

Fig. 1.1 Assembled rigid bronchoscope. Most models of rigid bronchoscopes must be fully assembled for use. A fully assembled rigid bronchoscopy is comprised of several interchangeable pieces: barrel (B) with beveled tip (A), multifunctional head (C), lateral port of multifunctional head (D), adapter for jet ventilation (E), telescope (F), light source (H), and camera (G)

An illuminated optic is typically paired with a camera to allow the endoscopic image to be projected on a display. The traditional way of direct visualization via the eyepiece of the optic is rarely used nowadays. Depending on the video processor unit available at a given institution, there are a variety of adapters that can be used to attach the optic and light source to the monitor.

The assembly of the barrel, multifunctional head, and optic (with light source) allows for the formation of a robust tool that is essential in the armamentarium of airway specialists (Fig. 1.1).

Flexible Bronchoscope

Flexible bronchoscopes have undergone tremendous evolution over the last four decades. Most practitioners currently use a true video bronchoscope, which did not become available until 1987 [1]. It was at that time that a CCD chip was able to be miniaturized and used within an endoscope. Older models used optical fibers as a conduit for image transmission through the insertion tube and handle, to an eyepiece or display [12].

The latest generation of bronchoscopes allows options for magnification, insertion tube rotation, use of narrow band imaging, and up to 210-degree tip angulation [13]. Although specifications vary considerably among manufacturers, the FB is comprised of several key components: cable for light source and imaging processing, control level, suction channel, catheter insertion channel, and the insertion tube. The insertion tube contains important parts that allow the FB to visualize, illuminate, and maneuver (Fig. 1.2). Flexible bronchoscopes with fiber-optic bundles are still used but mostly in the context of hybrid bronchoscopes [1]. In these models, the insertion tube contains the fiber-optic bundle, which transmits images to the CCD chip that is housed in the control head.

The size of the working channel is an important variable in the selection of a FB for a given procedure. Flexible bronchoscopes with a large working channel (2.8 mm) allow for more meaningful suctioning and easier passage of instruments

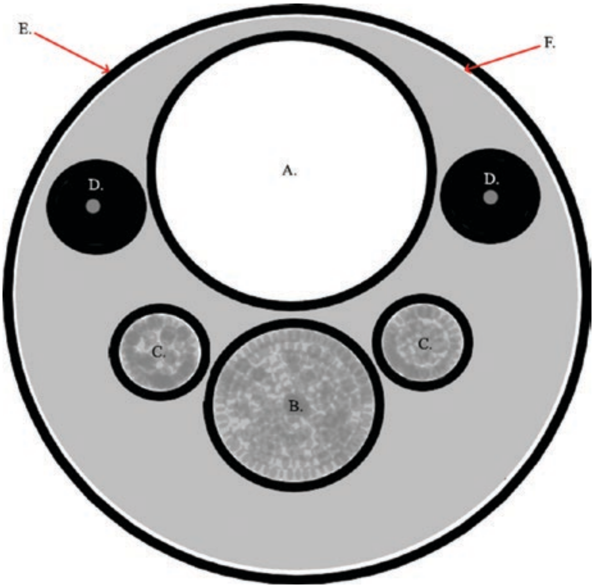

Fig. 1.2 Cross-sectional schematic of the insertion tube of a flexible bronchoscope. The insertion tube of flexible bronchoscope houses several key fragile components. The instrument channel (A) allows for suctioning or passage of tools. The image guide fiber bundle (B) allows for visualization. The light guide fiber bundles (C) allow for illumination. Angulation wires (D) allow for anteflexion and retroflexion of the distal end of the flexible bronchoscope. These components are wrapped in a metal mesh (F), which is surrounded by the external covering of the insertion tube (E)

via the working channel. Although there are tools that can be passed through a 2.0 mm working channel, the applications remain limited. For example, a 1.9 mm cryoprobe can be passed through a 2.0 mm working channel, but the significant amount of friction between the probe and inner walls of the working channel may make it challenging to use.

Contemporary Applications

Rigid bronchoscopy is a procedure that is performed by trained interventional pulmonologists, thoracic surgeons, and otorhinolaryngologists. It has a wide array of applications in the management of both benign and malignant airway diseases. The structure of the barrel provides a large working field within the major airways such as the trachea, mainstem bronchi, and bronchus intermedius. The complementary use of the FB and RB within a single procedure allows access and the ability to intervene on many areas of the tracheobronchial tree. For interventional pulmonologists and thoracic surgeons, both bronchoscopes are invaluable tools in a variety of clinical scenarios: central airway obstruction, tracheobronchial stent management, massive hemoptysis, and airway foreign bodies [14].

Central Airway Obstruction

Historically, 20–30% of patients with primary lung cancer developed central airway obstruction [15]. More contemporary data suggest an incidence around 13% [16]. In addition to malignancy, there are a variety of benign disorders that can compromise central airways: post-tracheostomy tracheal stenosis, post-intubation tracheal stenosis, idiopathic subglottic stenosis, complications of lung transplantation, or complications of inflammatory disorders [17, 18]. The most common cause of benign central airway stenosis is post-intubation traumatic stricture [19]. Anatomically, central airway obstruction can be classified by its extent and type. Extent is determined by the length of involvement; the type may be categorized as extrinsic, intrinsic, or mixed.

It is estimated that management of central airway obstruction accounts for 70% of all rigid bronchoscopies performed [20]. The RB has a variety of advantages in the management of central airway obstruction. The large barrel can be used to secure, core, and dilate the airway. It also acts a passageway for the FB and other endoscopic tools. More recently, the RB has been used as a conduit for application of spray cryotherapy in the management of central airway tumors [21]. The barrel provides a large egress channel for nitrogen to escape, which mitigates the risk of the development of pneumothorax (Fig. 1.3). This risk is present since the gas expands by a factor of several hundred once released from the catheter [22].

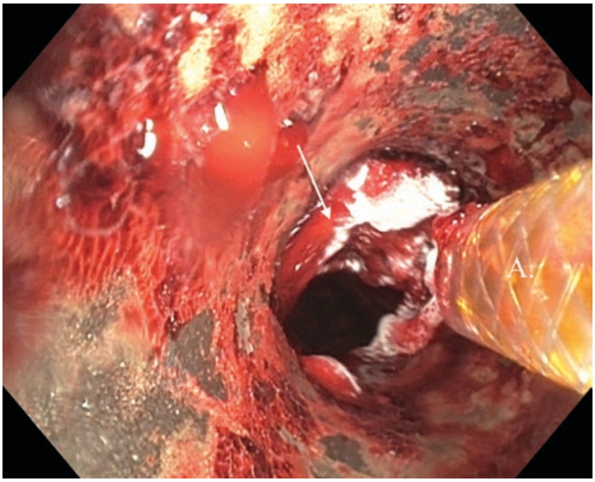

Fig. 1.3 Rigid bronchoscopy with spray cryotherapy. The barrel of the rigid bronchoscope allows for the procurement of a relatively large, secure working field within the airway. This is advantageous in a variety of scenarios. When performing spray cryotherapy, the rigid bronchoscope provides for a large egress channel. This is essential since the liquid nitrogen that exits the distal tip of the cryotherapy catheter (A) expands several hundred-fold while freezing the target (frost highlighted by the white arrow). Without adequate egress, this rapid expansion poses a risk for pneumothorax development secondary to barotrauma

The RB has advantages when performing ablative therapy. It allows the concurrent use of multiple instruments, including a rigid suction catheter. In this scenario, an ablative therapy such as ND:YAG laser can be used to devitalize a tumor while the large bore suction catheter is in place to quickly control any bleeding. Timely use of the RB has important implications for patients with central airway obstruction. In a retrospective study that evaluated 32 patients with central airway obstruction (malignant or benign) requiring an admission to the intensive care unit, emergent rigid bronchoscopy with dilation, laser debulking, or silicone stent insertion led to improvements in clinical status. Twenty (62.5%) patients were able to be immediately transferred to a lower level of care after intervention [23].

Flexible bronchoscopy also has applications in central airway obstruction. When inserted through an endotracheal tube or laryngeal mask airway, it can serve as a useful tool in selected patients with central airway obstruction. Generally, a FB is more readily available than a RB. Of the 1115 therapeutic procedures captured in the AQuIRE Registry, 382 (34%) were performed with a FB [24]. Flexible bronchoscopy has the advantage of being able to be performed under moderate sedation [25]. Most endoscopic ablative tools (electrocautery, argon plasma coagulation, certain lasers, cryoprobe, and spray cryotherapy) can be used through the working channel of a FB. Mechanical debulking using flexible forceps is possible, although it is not as effective as using the dedicated RB debulking forceps [25].

Stent Management

Rigid bronchoscopy is an extremely useful tool in airway stent management. A RB can be used to place, revise, or remove stents [26]. Traditional management of silicone stents requires the use of a RB. Case reports of silicone stents being placed without the use of a RB have been published, but this is not generally recommended [27].

To deploy a silicone stent, a stent of an appropriate size, shape, and length is selected. This stent is folded, lubricated, and loaded into a stent delivery device. The delivery device passed through the barrel of the RB; the handles of the delivery apparatus are manipulated to deploy the stent at its intended site. Large grasping forceps are used to change the stent's position post-deployment (Fig. 1.4). The same forceps can be used to remove a silicone or other type of stent [28].

Self-expanding metallic stents can be deployed via the use of a FB or RB. Depending on the size of the stent, some may even be deployed under direct visualization through the working channel [29–31]. Due to increased maneuverability of the FB, lobar stenting may be achieved [32–34]. Most stents placed via a FB are done via guidewire and the use of fluoroscopy. Stent deployment with the exclusive use of the RB is limited to the trachea, mainstem bronchi, or bronchus intermedius.

The RB is a powerful tool that can be used for the removal of stents [35]. This is particularly important in the management of uncovered metallic stents that have been in the airway for some time, as there is often granulation tissue and scarring

Fig. 1.4 Silicone stent placement. The rigid bronchoscope is an essential tool in the management of silicone tracheobronchial stents. The internal diameter of the barrel provides a conduit for stent delivery, repositioning, or removal. Grasping forceps (A) can be used to manipulate the silicone stent to achieve optimal placement

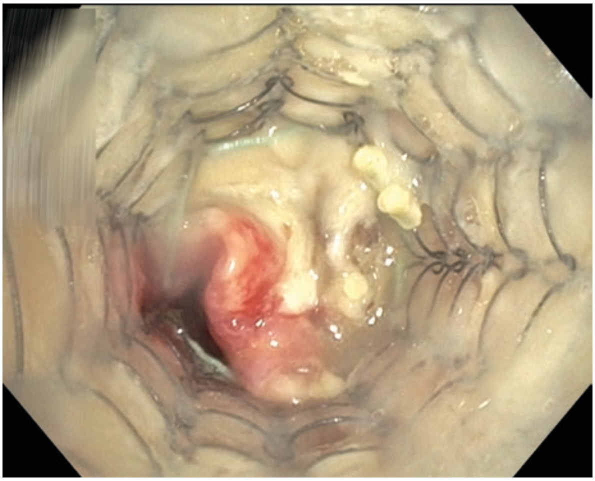

Fig. 1.5 Metallic stent complications. Stent-related complications occur commonly, and they require prompt intervention. Granulation tissue formation is a well-known complication. This endoscopic view showcases a near-complete tracheal obstruction due to an admixture of in-stent granulation tissue and mediastinal tissue. This patient had a metallic tracheal stent in situ for several months, with radiographic evidence of airway dehiscence

[36]. These stents can get completely embedded into the airway [37]. In scenarios such as airway compromise due to granulation tissue overgrowth, hemoptysis due to stent-related complications, or stent-related infections, these stents must be removed (Fig. 1.5). Removal of these stents can be very challenging and can lead to complications as severe as loss of the airway and death. In July of 2005, the US Food and

Drug Administration issued a warning pertaining to the use of covered and uncovered metallic tracheal stents in patients with benign airway disorders [38]. The use of a RB in these situations allows for the securement of a larger, secure working field. Even with the use of the RB, manipulation of these stents and surrounding tissue can cause significant bleeding or the formation of a defect in the airway.

Follow-up surveillance bronchoscopies for post-stent placement monitoring can be easily performed via FB. However, there is no clear data to suggest these bronchoscopies are needed. One study suggest that follow-up surveillance bronchoscopy within 4–6 weeks of stent placement may be useful. It is important to know that only half of the follow-up bronchoscopies in this study were performed exclusively with the use of a FB, the rest were with a RB or a FB in combination with a RB [39]. Another study suggests that routine surveillance bronchoscopy after stent insertion is not an effective practice [40]. Stent-related complications were detected in only nine asymptomatic patients, less than half of which needed a therapeutic intervention.

Massive Hemoptysis

Massive hemoptysis is a medical emergency. It is a life-threatening condition that can lead to severe hypoxia, hemodynamic stability, and death. There is no clear consensus of what volume of blood is considered massive hemoptysis. Common causes include lung cancer, bronchiectasis, and certain pulmonary infections [41]. In clinical practice, a multimodality approach is needed to diagnose and manage massive hemoptysis [42]. The use of chest computed tomography and the FB can help with localization of bleeding and guide intervention [41].

Rigid bronchoscopy can be a useful therapeutic tool in massive hemoptysis. It allows for the securement of the airway with a large working channel in which multiple therapeutic tools can be used simultaneously. In scenarios of unilateral bleeding, the side ventilation ports of the barrel can be used to provide adequate ventilation to non-bleeding lung, while the distal end of the barrel is engaged in and isolating the bleeding lung. In addition to identifying and treating bleeding, techniques via rigid bronchoscopy can be useful to clear the airway after bleeding has ceased. Tools such as the rigid suction catheter and cryoprobe are effective in removing large clots from the major airways.

Both the FB and RB can be used independently or in tandem for managing hemoptysis. Flexible bronchoscopy can identify the source in a majority of cases presenting with massive hemoptysis; however, its diagnostic yield is lower in identifying a source for mild or moderate cases [43]. While the FB is useful for airway examination and localization of bleeding, its interventional scope is limited. Perhaps one of the best uses is in blocking the site of bleeding with a balloon occlusion device [44].

In combination with bronchoscopy, it is essential to identify the underlying cause of bleeding and arrange for concurrent intervention such as radiation therapy or bronchial artery embolism embolization [45, 46].

Foreign Body Removal

Typically, foreign body aspiration occurs in children, the elderly, or adults with neurological or neuromuscular disease [47]. The collection of foreign bodies removed by Chevalier Jackson is on display at the Mütter Museum in Philadelphia, Pennsylvania. This display includes over 2000 objects that were removed during Dr. Jackson's career [8].

Several points of controversy exist when deciding using either a RB or FB for the removal of foreign bodies within the adult airway. A similar debate exists in the gastroenterology literature [48]. In pediatric medicine, many consider foreign body removal via rigid bronchoscopy as the standard of care [49]. This is because the airways of a child are narrower, and there is a higher risk of complete airway obstruction. The RB barrel allows for a secure ventilation route, with a lower chance of complete airway obstruction. In contrast, there is data to support a FB centered approach for the removal of foreign bodies in pediatric airways [50].

When used appropriately, a FB has a high success rate in the removal of inhaled foreign bodies. In most instances, flexible bronchoscopy can be considered an appropriate initial approach for the extraction in adults. Rigid bronchoscopy may be the preferred approach in scenarios presenting with respiratory distress, when extraction is expected to be challenging, or flexible bronchoscopy has already failed [47]. Rigid bronchoscopy is most useful for removal of foreign bodies from the major or proximal airways (trachea, left or right mainstem bronchus, or bronchus intermedius). It has limited application in more distal airways, which is an area in which flexible bronchoscopy can be useful.

Data has shown that foreign body removal with a FB has a high success rate. A retrospective bronchoscopy database has shown that over 90% of foreign bodies were successfully removed with no major complications, using a FB [51]. In general, the use of FB allows for a more thorough examination of the airways. It is also very useful in the clinical scenarios in which the neck cannot be manipulated, which would prevent intubation via a RB [47].

Foreign bodies that could damage the airway (thumbtacks, nails, glass, etc.) need to be removed with extreme caution, often necessitating the use of the protective stainless steel RB barrel or an endotracheal tube [50]. Larger foreign bodies may not be able to be removed using a FB endotracheal tube. These must be removal via the barrel or the RB or be engaged at the distal end of the barrel and removed en bloc with the RB [50].

Contraindications

There is significant overlap in the list of contraindications for flexible and rigid bronchoscopy. A majority of which are relative, and they are summarized in Table 1.1. Severe respiratory failure may preclude safe performance of therapeutic bronchoscopy. In some instances, extracorporeal life support may be used to help facilitate bronchoscopy. At present, related data is limited to case reports [52–54].

Table 1.1 Contraindications for flexible and rigid bronchoscopy

	Flexible bronchoscopy	Rigid bronchoscopy
Absolute	Refractory hypoxemia, hemodynamic instability, lack of informed consent, inexperience of operator, life-threatening arrhythmias	Limited mouth opening, unstable midline facial fractures, obstructions at the larynx, and limitation in cervical spine hyperextension or rotation (caution in patients with rheumatoid arthritis and atlantoaxial subluxation and instability), absolute contraindications for flexible bronchoscopy
Relative	Severe hypoxemia, recent myocardial infarction, coagulopathy, pulmonary hypertension, elevated increased intracranial pressure, pregnancy	High oxygenation requirements with high PEEP needs, relative contraindications for flexible bronchoscopy

Abbreviations
FB Flexible bronchoscope, *RB* Rigid bronchoscope, *Nd:YAG* Neodymium-doped yttrium aluminum garnet, *CCD* Charge-coupled device

There often concerns surrounding the performance of therapeutic bronchoscopy (flexible or rigid) in patients with space-occupying brain lesions. This is not a rare scenario since bronchoscopy is often performed in patients with metastatic cancer. In a study by Grosu et al., 12 patients with space-occupying lesions underwent rigid bronchoscopy with general anesthesia, without complication. Due to a small sample size, the results cannot be generalized. Larger studies are needed to assess the safety of bronchoscopy under general anesthesia in this specific patient population.

Complications

Overall, therapeutic bronchoscopy is a safe procedure. Whether performed with a FB or a RB, the most concerning complication is the development of malignant cardiac arrhythmias secondary to severe hypoxia. Local complications with flexible bronchoscopy are usually related to use of concurrent therapeutic tools: airway tear with balloon dilation, hemorrhage with cryotherapy, or airway fire with hot ablation modalities [55, 56].

With the use of a RB, traumatic complications such as tracheal or bronchial wall rupture may also occur. Less severe complications such as injury to the teeth, gums, or the larynx can often be avoided with a careful intubation technique.

The AQuIRE Registry captured 1115 therapeutic bronchoscopy procedures performed over 15 centers within the United States [24]. Only 44 complications were reported, 24 of which resulted in an adverse event. Six complications resulted in death. Most patients in this registry had primary lung cancer. It is important to note there was significant variation in use of rigid bronchoscopy among the contributing centers. Outcomes related to each modality of bronchoscopy are detailed below.

When performed by appropriately trained individuals, rigid bronchoscopy is a safe procedure. In a prospective study that analyzed 3449 procedures using a RB [57], major complications occurred in 48 procedures; hypoxemic respiratory failure was the most serious complication. Data from the AQuIRE Registry also showed low complication rates among therapeutic procedures performed with a RB (*n* = 733) [24]. The overall complication rate was 3.4% (25 patients); 0.5% (four patients) had a complication that resulted in death. Most patient underwent rigid bronchoscopy as their first therapeutic bronchoscopy (*n* = 542). Of this group, 17.5% (95) died within 30 days. In a retrospective study that analyzed 775 rigid bronchoscopies between 1992 and 1999 at a tertiary care hospital, 103 patients had complications (13.4%), but most were mild [58]. Three deaths occurred; two were due to severe hemorrhage and one due to respiratory failure. An overall procedure-related mortality rate was reported to be 0.4%. Most of the patients in this study had advanced lung cancer. On analysis, risk factors associated with severe complications included patients with underlying respiratory, cardiac, or hematologic disorders and patients with tumors or foreign bodies in their airway. Patients with neoplastic carinal involvement were at the highest risk of developing complications.

In a single-center retrospective study that evaluated 79 therapeutic rigid bronchoscopy procedures, major bleeding occurred in 3.8% of patients and postoperative respiratory failure occurred in 5.1% of patients [59]. The overall 30-day mortality rate was 7.6%. Ninety percent of patients in this study had malignant disease.

The AQuIRE Registry also captured data for therapeutic bronchoscopy performed with a FB (*n* = 382) [24]. A 5% overall complication rate was reported in this group. Less than half of these lead to an adverse event. Complication rate leading to death was also low (0.5%). In summary, a large body of medical literature attests to the safety of therapeutic airway interventions being performed using the RB or FB.

Training and Future

Appropriate training is essential to attaining procedural competency. Bronchoscopy is commonly performed by a variety of specialties (critical care medicine, pulmonology, anesthesiology, general surgery, otorhinolaryngology, and thoracic surgery); flexible bronchoscopy training is highly variable. Metrics used to assess competency and minimum procedural requirement vary by professional organization. The Accreditation Council for Graduate Medical Education Program Requirements for graduate medical education in Pulmonary Disease and Critical Care Medicine states that fellows must perform at least 100 flexible bronchoscopy procedures during their training [60].

The joint American Association of Bronchology and Interventional Pulmonology, Association of Interventional Pulmonary Program Directors, American College of Chest Physicians, American Thoracic Society, and Association of Pulmonary and Critical Care Medicine Program Directors summary addresses the minimum number of therapeutic procedures that must be performed at a given institution for accreditation of an interventional pulmonology fellowship [61]. A recommendation of an annual institutional case volume of 50 rigid bronchoscopies was made.

However, readiness for independent practice is determined by the program director of the interventional pulmonology fellowship. Australia, some European nations, and China have their own forms of formal training or certification [62].

Simulation-based training appears to be beneficial in learning flexible bronchoscopy skills [63–65]. A study by Mallow et al. showed that bronchoscopists with former video game playing experience may have lower airway collision rates [66]. A systemic review and meta-analysis concluded that simulation-based bronchoscopy training is effective [67]. Overall, simulation training was found to be beneficial when compared to no intervention. The differences between training and clinical instruction were not significant [67].

There are no validated metrics to assess therapeutic flexible bronchoscopy skills. There is some literature that speaks to training with a RB. A study among anesthesiologists suggested that the technical skill of rigid bronchoscopy can be acquired within ten repetitions on a manikin [68]. The scoring system RIGID-TASC has been studied to assess the skills of basic rigid bronchoscopy. It is a checklist-based tool that assesses key steps in rigid bronchoscopy, from bronchoscope assembly to bronchoscope guidance and time to procedure completion. Scores can distinguish rigid bronchoscopy skills among novice, intermediate, and expert operators [69].

Although the design of the FB has been undergoing significant evolution, RB design has remained relatively stagnant. Novel robotic rigid bronchoscopy platforms are being evaluated. A study on ex vivo animal models and cadavers has shown that a robotic rigid bronchoscopy platform was able to successfully reduce central airway obstruction and force applied to a patient's head and neck [70].

Conclusions

In summary, the FB and RB work in tandem to successfully manage a variety of airway diseases. The ability to be facile with both tools is an essential skill of any physician who manages complex airway diseases. Both instruments have evolved over the course of the past few decades. The list of accessory equipment that can be paired with either of these bronchoscopes continues to grow. There is significant overlap in their indications; complementary use in the appropriate clinical scenarios can lead to positive outcomes with low complication rates.

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Chapter 2
Biopsy for Diffuse Lung Diseases: Surgical Vs Cryobiopsy

Stefano Gasparini, Martina Bonifazi, and Armando Sabbatini

Introduction

The term "diffuse parenchymal lung diseases (DPLDs)" includes a wide spectrum of heterogeneous entities with different etiologies, prognosis, as well as treatment options. Due to the recent progresses in therapeutic landscape of DPLPs, the distinction between idiopathic pulmonary fibrosis (IPF), the most prevalent and severe form, and other diseases has become essential for a proper management [1]. However, an accurate diagnosis of IPF is a challenging process, as, according to the ATS/ERS guidelines [2], it requires an integrated multidisciplinary approach involving pulmonologists, radiologists, and, in more complex cases, also pathologists. The diagnostic work-up of DPLDs, indeed, includes a thorough clinical history, mainly focused on familial background, environmental/occupational exposure and drug intake, a careful physical examination, lung function tests, high-resolution computed tomography (HRCT), bronchoalveolar lavage, and, in case of still inconclusive results, a lung tissue sample. In this context, the role of conventional transbronchial lung biopsy is limited to the exclusion of specific disorders (i.e., sarcoidosis, carcinomatous lymphangitis, organizing pneumonia), since the small sample size, the rate of crush artifacts, and the high likelihood to sample mostly centrilobular areas do not allow to properly identify more complex and spatially heterogeneous morphological patterns [3].

S. Gasparini (✉) · M. Bonifazi
Department of Biomedical Sciences and Public Health, Università Politecnica delle Marche, Ancona, Italy

Pulmonary Diseases Unit, Azienda Ospedali Riuniti, Ancona, Italy
e-mail: s.gasparini@univpm.it

A. Sabbatini
Thoracic Surgery Unit, Azienda Ospedali Riuniti, Ancona, Italy

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