Jose Pablo Díaz-Jimenez
Alicia N. Rodriguez
Editors

Interventions in Pulmonary Medicine

Second Edition

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Alicia
To Manuel and Francisco, of course. To my sisters Maria, Fatima, Elsa and Adriana. To Pablo, friend and teacher.

Pablo
To my wife Mercedes, to whom I owe so much, and who is by my side on the way of life. To my father my best friend. To my sisters Yolanda, Delia and Dolores with love. To my children Arturo, Cristián, Carlos and Pablo. To my grandchildren Elia, Lluc, Quim, Ferran and Bruna, from whom I am learning to live. To Alicia Rodriguez, my dearest friend and superb pulmonologist, the true architect of this book.

To my mentors: Dr. D. Cortese, Dr. UBS Prakash and especially to Dr. JF Dumon who directed my first steps in interventional pulmonology.

Foreword

The demand for a second edition of this fine textbook after only 3 years shows the increasing importance of interventional bronchology in pulmonary medicine. For 70 years after its invention by Killian in 1897, rigid bronchoscopy remained restricted to a limited number of specialized hospitals. Only after the introduction of the flexible bronchoscope by Ikeda in 1966 did bronchoscopy became widely applied. This was promoted by the early work of pioneers, by a European group, including J. P. Diaz-Jimenez in Spain, J. F. Dumon in France, and S. Cavliere in Italy. The preservation of skills in rigid bronchoscopy in combination with the flexible instrument proved ideal, especially in developing treatment of the central airways such as mechanical resection, using lasers, stents, etc. As Freiburg in former times, Marseille, Barcelona, and, briefly afterward, also Heidelberg, Germany, became European training Meccas for physicians from all over the world. I am calling myself fortunate for experiencing such exciting times and counting these pioneers among my friends, apart from having been able to contribute (e.g., EBUS, SEMS, and EMN).

Due to exponential development in imaging and instrumentation technology during the last three decades, bronchology has developed into an important specialty in its own right within pulmonary medicine. The champions have become numerous worldwide as is reflected by the list of contributors in this book. Many associations for bronchology and interventional pulmonology have been founded on all continents and are connected under the umbrella of the World Association for Bronchology and Interventional Pulmonology (WABIP). Training centers have been established worldwide, where structured courses are offered and formalized tests provide credentials of proficiency. For those unable to attend on site, a digital training module is offered on the Internet.

All topics are covered within this concise textbook by renowned authors. The chapters cover the anatomical and technical basics as well as quality management. All current technologies for treatment of central airway obstruction are discussed. As especially in the diagnosis and treatment of lung cancer bronchoscopy is playing a major role, the concepts of screening, early detection, and staging for making sound decisions for therapy are described in extenso. This includes also the pleural space as far as is relevant for the pulmonologist. The final chapters deal with recent developments for intervention in benign diseases such as asthma and emphysema and in special indications.

The conclusion describing the history and the outlook into the future should encourage the next generation to carry the torch onward.

The book is not only a must for all physicians who take up the path to become interventional pulmonologists but also for every pulmonologist as interventional bronchoscopy has become such an important integrated part in pulmonary medicine. Knowledge of its indications and limitations is essential for intelligent decision-making. The authors can only be congratulated on their remarkable effort.

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Preface to the First Edition

Nothing beats the pleasure of seeing a finished work.

This book is a reflection of what we do every day in the endoscopy room, and it would not have been possible without the collaboration of the colleagues who have participated, sharing their knowledge and expertise to clearly set out the fundamental concepts of this wonderful interventional pulmonology world.

I have been working in the interventional area for more than 30 years, and one of the main concepts that I have learned is that success in daily work does not rely on one individual, but it is only achievable when everybody works with the conviction of being part of a team.

It would not be possible to perform a complex treatment such as releasing the airway from an obstructive malignant tumor without each and every team member's participation, applying their knowledge and abilities in a coordinated and complementary fashion. As team members, we all share responsibilities. I believe one of the main ones is to make the whole team function based on these three mainstays: coordination, communication, and complement, since they are the keys of a successful work.

Since the advent of bronchoscopy in 1887, the field of bronchology and interventional pulmonology has demonstrated its clinical value with amazingly rapid developments. The last three decades have brought to us spectacular advances in technology and their clinical applications, which have led to lifesaving therapies. We can predict that we will see newer clinical applications and improvement in established techniques in the near future. These dynamic changes will bring together the scientists and clinicians interested in our specialty and further expand the field.

It is our duty to keep updating the state of the art and maintain a continuous progress. The scientific and clinical training of the respiratory endoscopist must rest on solid principles and remain in constant forward motion, and therefore, constant teaching and learning become our obligations.

During all these years, we have received pulmonary fellows from all continents who have spent long periods of time with us or have attended our courses or conferences, teaching them interventions and also learning from them. We have also learned from very respected physicians of the interventional pulmonology field who have honored us with their presence, sharing their experiences and making this learning process extremely easy, as if we were in a family reunion listening and exchanging everyday experiences. At

the end of the day, we were all enriched, and I believe all our patients benefited from our sessions and discussions.

Experience does not come only as a consequence of performing many procedures but also from having an open mind and listening to the advice and suggestions from other colleagues. The learning process takes a lifetime. At the beginning, we are all learners, and as time goes by, it becomes our turn to take the position of the teacher and to contribute to the growing number of fellows and residents interested in endoscopic procedures. What would have occurred if retired from daily practice Killian, Jackson, Andersen, Ikeda, Zavala, Hayata, Kato, Cortese, or Dumon had not transmitted their experiences to the rest of the scientific community? It would have been much more difficult for us to arrive to our present state of knowledge. However, the generosity of all of them made our way much easier.

Bertrand Russell said it is good from time to time to think on the present as if it were the past and consider which of the elements of our time will enrich the permanent deposit of the universe and which ones will live and give life when our generation has disappeared. Having this contemplation, the human experience transforms, and the personal experience vanishes.

With this in mind, I believe the teaching and learning process is crucial, and they both have to be taken with humility. To our teachers, we always owe gratitude and respect, and when we become teachers, it is important to be generous, recognize limitations, and transmit what is worth, keeping always as a goal to benefit our patients in every possible way.

Following this line, Alicia and I would like to take this opportunity to thank the many teachers and colleagues around the world who helped us along the way, with their advice and continuous support:

- Dr. Udaya Prakash and Eric Edell form Mayo Clinic
- The coworkers from the Bronchoscopy Department at Bellvitge University Hospital in Barcelona, A. Rosell, R. Lopez, and N. Cubero, and from the MD Anderson Cancer Center Team in Houston, R. Morice, G. Eapen, C. Jimenez, D. Ost, and B. F. Dickey
- The Pulmonary Department Team at Lahey Clinic in Massachusetts
- The Pulmonary Department Team at Clinica Colon in Mar del Plata: L. Araya, N. Baillieau, S. Ruiz, C. Materazzi, M. Rocha, and B. Nuñez

And finally, our especial thanks go to all the colleagues who participated in this work, generously sharing their wisdom and making possible this small addition to the art of respiratory endoscopy. It is our hope that this book will contribute to improve our daily interventional pulmonology practice.

Barcelona, Spain Jose Pablo Díaz-Jimenez

Preface to the Second Edition

The future belongs to those who learn more skills and combine them in creative ways. —Robert Greene, Mastery

When we presented the first edition of *Interventions in Pulmonary Medicine*, both Pablo and I thought it was a great honor to include in our book the most prominent colleagues in the area, updating the state of the art in their field of expertise.

Incredible to us, we now have a second opportunity to review the topics, and we are deeply grateful to have many great professionals who generously shared their knowledge with all of us improving our medical practice and, most importantly, improving the lives of people who consult us looking for help.

It is a great privilege to practice medicine. It is in our hands to do the best continuously updating what we know. That goes hand in hand with the warm touch, empathy, and compassionate conversation with the fellow suffering human being who is in front of us. Undoubtedly, this part of medicine is the most satisfactory feature in the life of a doctor and what patients value the most since it helps them to better endure their moments of illness.

We therefore want to dedicate this book to our patients and thank them for being our daily reason to be better at what we do.

Medical knowledge is crucial in our service path, and with this idea, we present this new edition, as a growth tool for all those who perform interventions in pulmonary medicine.

We also owe our thanks to our work teams, who support and share our ideals, contribute daily to solve issues, and pay attention to details making harmonious and effective functioning at the workplace. A doctor cannot be good without a support system, and in that sense, the work team is a family where each one brings a different and necessary quality.

We also want to mention and honor our teachers, those of whom we learned both what to do and what not to do. Undoubtedly, their contribution of knowledge, work ethic, and human qualities have had a great impact in the way we practice every day at the consultation and in the operating room.

Finally, we also dedicate this edition to physicians in training, hoping that what has been turned into these pages become an important contribution coming from experienced professionals with decades of medical practice. Their advice and reflections will undoubtedly modify some practices, they certainly have improved Pablo's and mine. We wish that the medical practice

of those who are beginning this path will be as satisfactory as ours and that we will all have the main objective to benefit our patients in every possible way. We also encourage younger doctors to develop new ideas and perfection techniques, so that the area of interventionism continues to grow with the younger generation.

We hope the reading of this edition will be enjoyable and useful for everyone. It was an honor to us to have well-known colleagues who are the true protagonists of this book and once again to make a small contribution to the art and science of interventional pulmonary medicine.

Mar del Plata, Argentina — Alicia N. Rodriguez
June 2017

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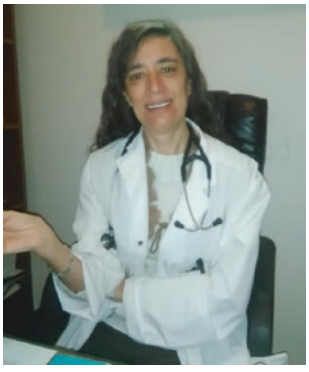
Jose Pablo Diaz-Jimenez is head of the Pulmonary Department at Clinic Corachan, Barcelona, and Adjunct Professor in the Pulmonary Department at MD Anderson Cancer Center. He is also former Chairman of the World Association for Bronchology and Interventional Pulmonology (WABIP) and former President of the World Bronchology Foundation (WBF).



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Part VIII Interventions in Pulmonary Medicine: History and Future Perspectives

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Part I

Basic Endoscopy

Tracheobronchial Anatomy

1

Juan Antonio Moya Amorós
and Anna Ureña Lluveras

Trachea

Introduction

The trachea or windpipe is a tube of approximately 12 cm in length. Viewed laterally, it assumes an oblique course, running from superoanterior to inferoposterior, from 23° to 34° related to the body's major axis. It ends up by dividing into two bronchial tubes at the level of the tracheobronchial bifurcation, which usually has an angle of 60°. Changes in the degree of angulation can orient to diagnose some conditions located distally to the bifurcation such as enlarged lymph nodes or left atrium dilatation in mitral stenosis. The tracheal tube extends from C6 to C7 (limited by the cricoid cartilage superiorly) to D4–D5, approximately at 1 or 2 cm below a horizontal plane passing through the Louis sternal angle. Topographically its average length (12 cm as stated) is equally divided between the cervical and mediastinal region.

External Morphology

The external tracheal configuration is characterized by the presence of roughness due to incomplete cartilage rings that are staggered, horizontally and segmentally distributed. Usually 20 rings are identified in the trachea.

In the cervical region, the tube has a flattened shape posteriorly, due to the absence of cartilage, so that the predominant diameter is the sagittal or anteroposterior (approximately 16 mm), but inside the chest it predominates the transverse diameter (approximately 16 mm).

In the external tracheal wall, narrowing or depressions can be seen, produced by the imprint of organs in close proximity contacting to the tracheal wall. In the left side, two of them are visible: one due to the left thyroid gland lobe (neck) and the other one due to the aortic arch (mediastinum).

The posterior membrane closing the entire tracheal canal is flat, soft, and depressible; it is known as the *membranous pars* (Fig. 1.1).

The especial tracheal configuration and its elastic structure make it capable to elongate up to one third of its length. This fact is of particular interest for tracheal reconstruction surgeries.

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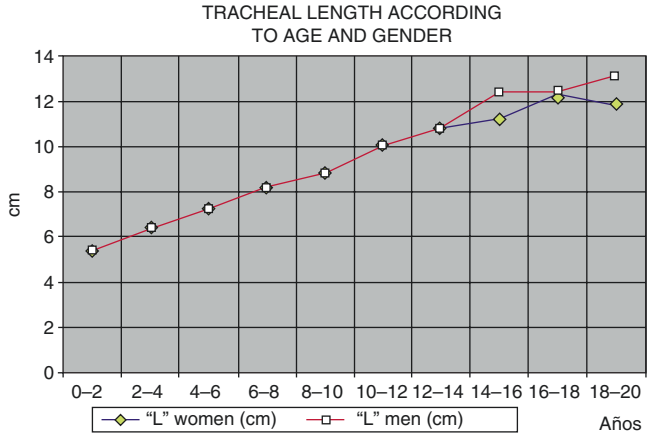
Fig. 1.1 Anterior view of the dissected trachea. Note the tracheal bifurcation angle of 60°, (*1*) anterior view: trachea and tracheal cartilage. (*2*) Tracheobronchial bifurcation. (*3*) Membranous pars or tracheal muscle. Unit of Human Anatomy and Embryology. Department of Pathology and Experimental Therapeutics. Universitat de Barcelona



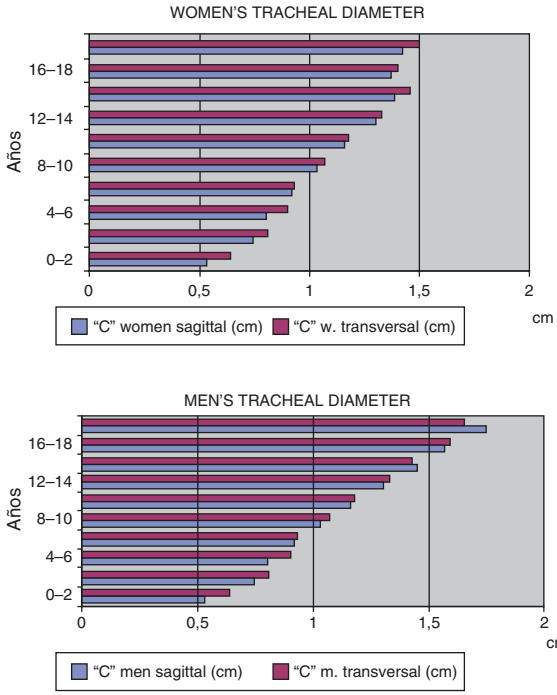
	"L" women (cm)	"L" men (cm)
0–2	5.4	5.4
2–4	6.4	6.4
4–6	7.2	7.2
6–8	8.2	8.2
8–10	8.8	8.8
10–12	10	10
12–14	10.8	10.8
14–16	11,2	12,4
16–18	12,2	12,4
18–20	11,8	13,1

Medium length of the trachea increases similarly in both genders until the age of 14. After that it only increases in men.

Fig. 1.2 Medium length of the trachea increases similarly in both genders until the age of 14. After that it only increases in men

Dimensions of the trachea vary primarily according to age and less so with gender. Figures 1.2, 1.3, 1.4, and 1.5 present the normal size variations in all three axes, internal size, area, and volume.

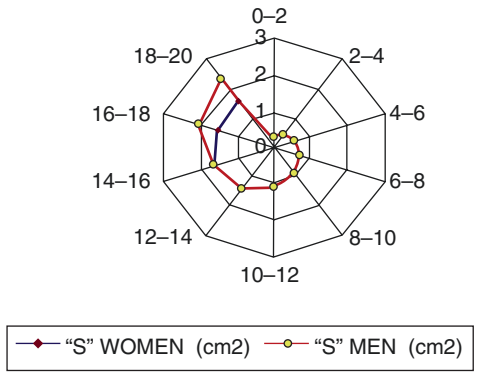
Among both genders, there are also differences in tracheal size especially in the sagittal and transverse axes, which are evident in tomographies and 3D reconstructions (Figs. 1.6 and 1.7).



AGE in years	*"C"* sagittal women (cm)	*"C"* transv. women (cm)	*"C"* sagittal men (cm)	*"C"* transv. men (cm)
0–2	0.53	0.64	0.53	0.64
2–4	0.74	0.81	0.74	0.81
4–6	0.8	0.9	0.8	0.9
6–8	0.92	0.93	0.92	0.93
8–10	1.03	1.07	1.03	1.07
10–12	1.16	1.18	1.16	1.18
12–14	1.3	1.33	1.3	1.33
14–16	1,39	1,46	1,45	1,43
16–18	1,37	1,4	1,57	1,59
18–20	1,42	1,49	1,75	1,66

Medium tracheal diameter increases similarly in both genders until the age of 14. After that it only increases in men.

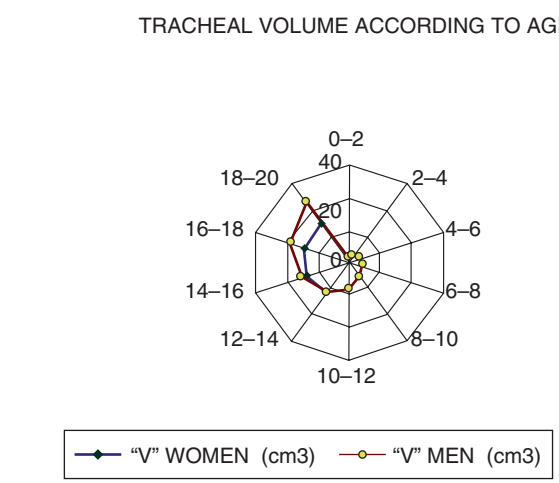
Fig. 1.3 Medium tracheal diameter increases similarly in both genders until the age of 14. After that it only increases in men



AGE	*"S"* WOMEN *(cm^2)*	*"S"* MEN *(cm^2)*
0–2	0.28	0.28
2–4	0.48	0.48
4–6	0.58	0.58
6–8	0.69	0.69
8–10	0.89	0.89
10–12	1.1	1.1
12–14	1.39	1.39
14–16	1.62	1.62
16–18	1,54	2,01
18–20	1,59	2,3

- Medium tracheal area increases similarly in both genders until the age of 14.
- At age 20, tracheal area is 44.6% larger in men than in women.

Fig. 1.4 Medium tracheal area increases similarly in both genders until the age of 14. At age 20, tracheal area is 44.6% larger in men than in women



AGE	*"V"* WOMEN *(cm³)*	*"V"* MEN *(cm³)*
0–2	1.57	1.57
2–4	3.11	3.11
4–6	4.16	4.16
6–8	5.67	5.67
8–10	7.87	7.87
10–12	11.1	11.1
12–14	15.4	15.4
14–16	18,2	20,2
16–18	18,8	25,1
18–20	18,9	30,3

* Medium tracheal volumen increases similarly in both genders until the age of 14

* By age 20, men's tracheal volume is 60% larger than women's.

Fig. 1.5 Medium tracheal volume increases similarly in both genders until the age of 14. By age 20, men's tracheal volume is 60% larger than women's

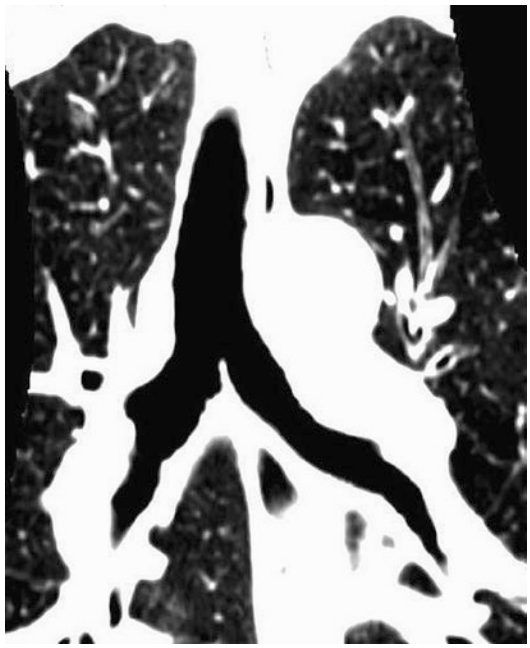


Fig. 1.6 : At age 20, men's sagittal and transverse tracheal axes are 23% and 11.4% larger than women's, respectively. Coronal computerized tomography: view of mediastinal trachea, tracheobronchial bifurcation, and main bronchi

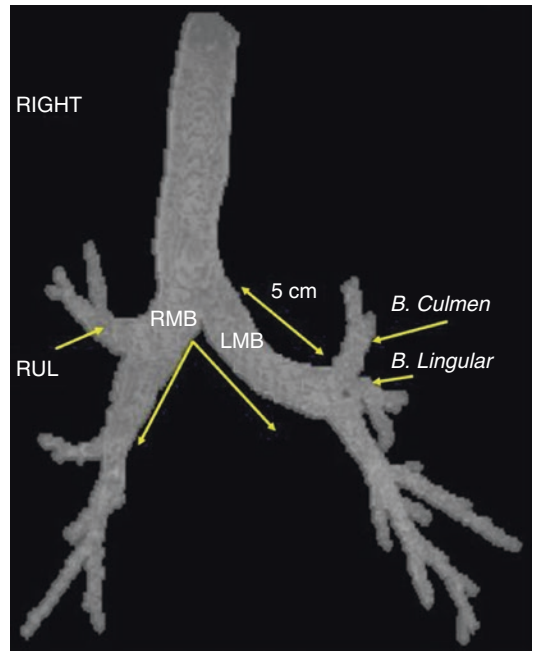


Fig. 1.7 Medium tracheal diameter is 1.5 mm larger in men than in women. Medium bronchial diameter is 1 mm larger in men. 2D tomographic reconstruction of the tracheobronchial tree. Note that the intracarinal angle is 60°. Lengths are 5 cm for the left main bronchus and 2.5 cm for the right main bronchus

Internal Morphology

The tracheal tube has two covers or layers.

Fibro-Chondro-Elastic Layer

It is a completely circular, soft, and elastic connective tissue fundamental matrix. It affects the entire circumference of the windpipe. It presents tiny holes that represent the point of vascular entrance or exit to and from inside the trachea.

Enclosed to this layer, there are bands of incomplete hyaline cartilage rings, horseshoe shaped. The cartilage forms about four fifths of the circumference of the trachea. Given that the posterior border of the trachea is formed by a fibromuscular membrane, tracheal cross-sectional shape is similar to a letter D, with the flat side located posteriorly. The tracheal muscles cross transversely and obliquely, forming a continuum of entangled fibers which constitute a large muscle: the common tracheal muscle. Contraction of this muscle produces adduction of the free cartilage edges, thus modulating the internal tracheal caliber. Wrapping the outer tracheal tube, we found the adventitia, a membrane that acts as a false pretracheal fascia. Between the adventitia and the tracheal wall, vascular and nervous branches are located, and they incorporate to the tracheal tube wall at the level of the interchondral spaces.

Mucous Layer

The trachea is lined by pseudostratified columnar epithelium that sits in an elastic *lamina propria* and covers the inside of the tracheal tube. Goblet mucous cells and small subepithelial glands that secrete into the luminal surface are interspersed among the ciliated columnar cells. The produced mucus adheres to inhaled foreign particles, which are then expelled by the action of cilia propelling the mucus lining upward towards the pharynx from which they can be coughed and sneezed out of the airway. At the end of the tracheal duct, when it is divided into the main bronchi, the mucosa presents a middle line elevation known as carina, similar to a medial ridge. The tracheal carina indicates the entrance to the right and left main bronchus (Fig. 1.8a–c).

Blood Supply

Arterial—it is established by two arterial systems on each side of the trachea, communicating the aorta artery with the subclavian artery:

- From the aorta, the left paratracheal ascending artery (Demel arteries) and the tracheobronchial esophageal artery. Of the latter, the right bronchial artery, the esophageal artery, and the right paratracheal ascending artery are born.
- From both subclavian arteries and inferior thyroid arteries and from these in turn emerge the right and left paratracheal descending arteries (Haller arteries).

Each paratracheal descending artery anastomoses with the paratracheal ascending artery of the corresponding side, closing the vascular circuit at the back of the tracheal wall and along its side edges. From these two vascular axes, tracheal perforating arteries are born that supply tracheal layers entering through the interchondral spaces.

Anatomo-Clinical Relationships

The trachea is related to their surroundings through the peritracheal fascia, as if it were a hanger between the neck and the mediastinum. Vascular and nerve structures hung from or are in contact with it.

Regardless of the anatomical details, the tracheal relationships from inside out are:

Fig. 1.8 (**a**) Cross section, trachea. (*1*) Respiratory cylindric epithelium and mucous glands. (*2*) Horseshoe-shaped cartilage, with a posterior opening. (*3*) Main layer, connective tissue fundamental matrix, surrounded by the adventitia. (**b**) Schematic illustration of the elements of the tracheal wall. (*1*) Poli-pseudostratified columnar epithelium, (*2*) gland drainage orifice, (*3*) gland duct, (*4*) submucous, (*5*) vagus nerve, (*6*) venules and arterioles. (**c**) Tracheal mucous gland. (*1*) Arteriole, (*2*) erythrocyte, (*3*) endothelial cell, (*4*) basement membrane, (*5*) Golgi apparatus of a goblet cell, (*6*) endoplasmic reticulum, (*7*) vacuole, and (*8*) mucus secretion

- Posterior: recurrent nerve, esophagus, and vertebral bodies covered by the deep cervical aponeurosis
- Anterior: thyroid gland, medium cervical aponeurosis, anterior jugular veins, and superficial cervical aponeurosis
- Lateral: thyroid gland, vessels and nerves, deep cervical aponeurosis, and superficial cervical aponeurosis (involving the sternocleidomastoid and trapezius muscles) (Fig. 1.9a, b)

The tracheobronchial bifurcation has similar topographical relationships in both genders, and it is located at 7 cm depth from the skin of the anterior midline chest (Figs. 1.10 and 1.11).

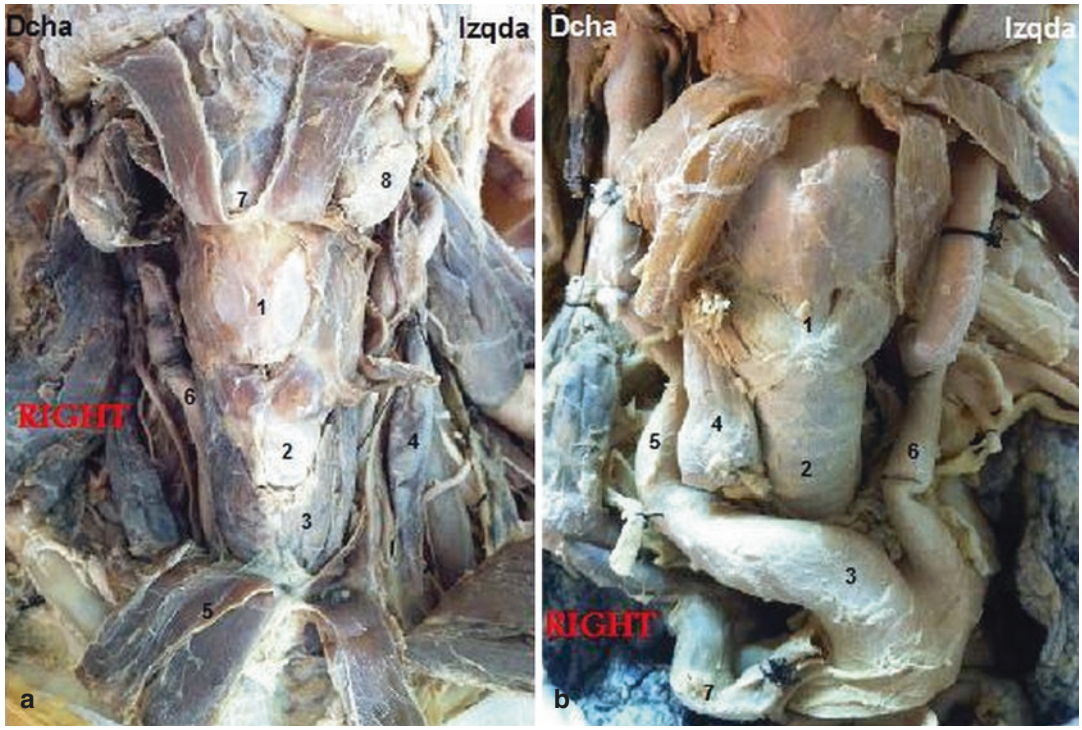


Fig. 1.9 (**a**) Dissection of the cervical trachea. (*1*) Larynx, (*2*) trachea, (*3*) left thyroid lobe, (*4*) left internal jugular vein, (*5*) right infrahyoid muscles, (*6*) right common carotid artery, (*7*) hyoid bone, and (*8*) left submandibular gland. (**b**) Dissection of the cervical trachea. (*1*) Larynx, (*2*) trachea, (*3*) brachiocephalic arterial trunk, (*4*) right internal jugular vein, (*5*) right common carotid artery, (*6*) left common carotid artery, and (*7*) left venous brachiocephalic trunk or innominate trunk. Unit of Human Anatomy and Embryology. Department of Pathology and Experimental Therapeutics. Universitat de Barcelona

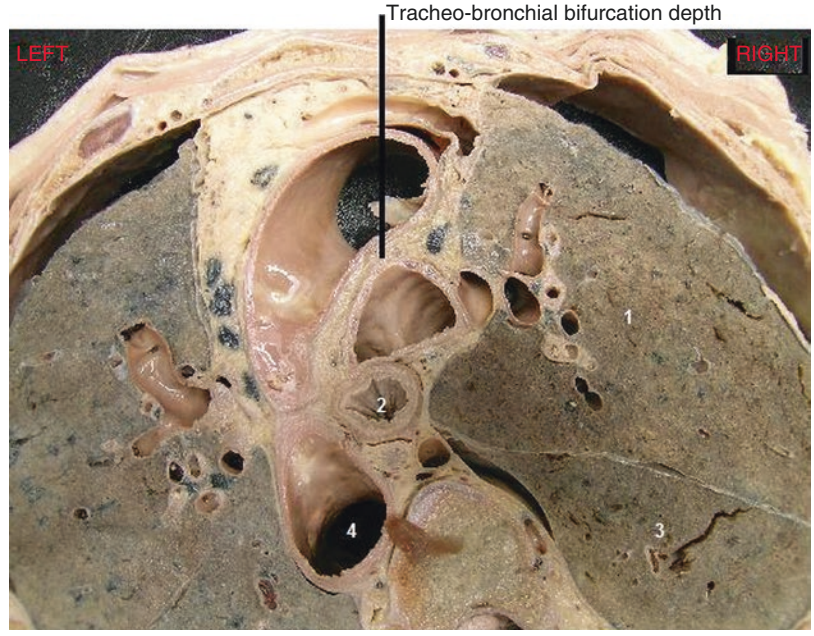


Fig. 1.10 Cranial view of thoracic cross section at the level of D4. Note the location of the tracheobronchial bifurcation at a depth of 7 cm from the surface. (*1*) Right upper lobe, (*2*) thoracic esophagus, (*3*) right lower lobe, 4: Descending thoracic aorta. Unit of Human Anatomy and Embryology. Department of Pathology and Experimental Therapeutics. Universitat de Barcelona