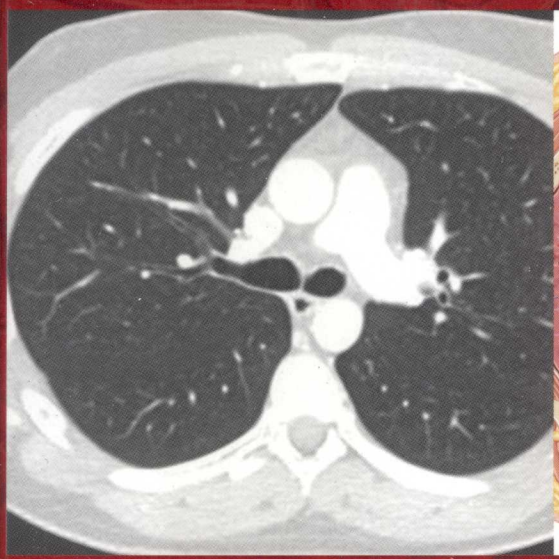
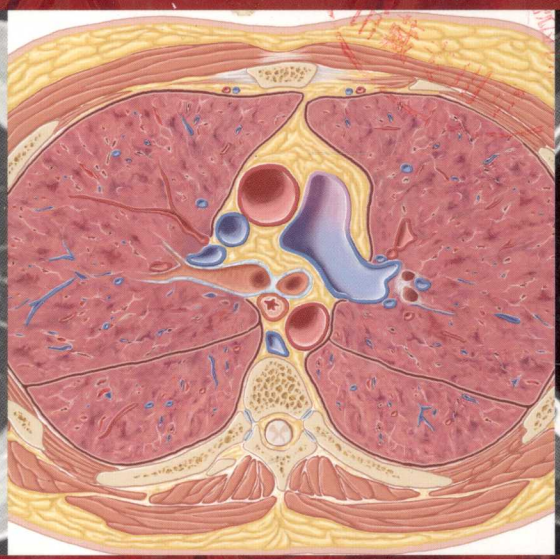
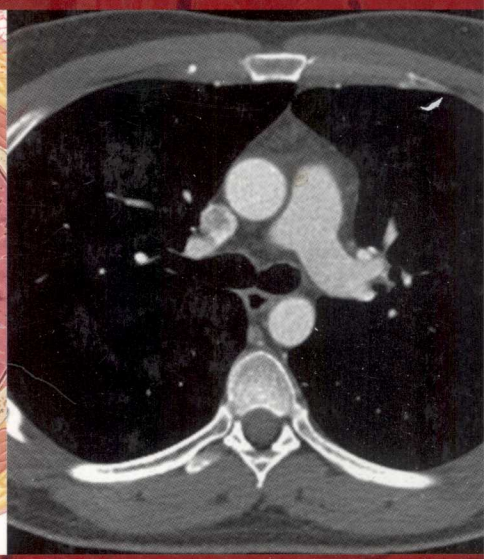
NETTER'S Correlative Imaging
Cardiothoracic Anatomy

MICHAEL B. GOTWAY

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NETTER'S
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About the Artists

FRANK H. NETTER, MD

Frank H. Netter was born in 1906 in New York City. He studied art at the Art Student's League and the National Academy of Design before entering medical school at New York University, where he received his MD degree in 1931. During his student years, Dr. Netter's notebook sketches attracted the attention of the medical faculty and other physicians, allowing him to augment his income by illustrating articles and textbooks. He continued illustrating as a sideline after establishing a surgical practice in 1933, but he ultimately opted to give up his practice in favor of a full-time commitment to art. After service in the U.S. Army during World War II, Dr. Netter began his long collaboration with the CIBA Pharmaceutical Company (now Novartis Pharmaceuticals). This 45-year partnership resulted in the production of the extraordinary collection of medical art so familiar to physicians and other medical professionals worldwide.

In 2005 Elsevier, Inc., purchased the Netter Collection and all publications from Icon Learning Systems. There are now more than 50 publications featuring the art of Dr. Netter available through Elsevier, Inc. (in the United States: www.us.elsevierhealth.com/Netter and outside the United States: www.elsevierhealth.com)

Dr. Netter's works are among the finest examples of the use of illustration in the teaching of medical concepts. The 13-book *Netter Collection of Medical Illustrations*, which includes the greater part of the more than 20,000 paintings created by Dr. Netter, became and remains one of the most famous medical works ever published. *The Netter Atlas of Human Anatomy*, first published in 1989, presents the anatomical paintings from the Netter Collection. Now translated into 16 languages, it is the anatomy atlas of choice among medical and health professions students the world over.

The Netter illustrations are appreciated not only for their aesthetic qualities but, more important, for their intellectual content. As Dr. Netter wrote in 1949, "... clarification of a subject is the aim and goal of illustration. No matter how beautifully painted or how delicately and subtly rendered a subject may be, it is of little value as a *medical illustration* if it does not serve to make clear some medical point." Dr. Netter's planning, conception, point of view, and approach are what inform his paintings and what makes them so intellectually valuable.

Frank H. Netter, MD, physician and artist, died in 1991.

Learn more about the physician-artist whose work has inspired the Netter Reference collection:

http://www.netterimages.com/artist/netter.htm

CARLOS MACHADO, MD

Carlos Machado was chosen by Novartis to be Dr. Netter's successor. He continues to be the main artist who contributes to the Netter collection of medical illustrations.

Self-taught in medical illustration, cardiologist Carlos Machado has contributed meticulous updates to some of Dr. Netter's original plates and has created many paintings of his own in the style of Netter as an extension of the Netter collection. Dr. Machado's photorealistic expertise and his keen insight into the physician/patient relationship inform his vivid and unforgettable visual style. His dedication to researching each topic and subject he paints places him among the premier medical illustrators at work today.

Learn more about his background and see more of his art at:

http://www.netterimages.com/artist/machado.htm

KRISTEN WIENANDT MARZEJON, MS, MFA

Kristen Wienandt Marzejon is a certified medical illustrator with an MS degree from the University of Illinois at Chicago's Biomedical Visualization graduate program. Her passion for both art and science from an early age makes her perfectly suited to this gratifying profession. She started her career as a staff illustrator at Rush University Medical Center in Chicago and then committed to self-employed status in 2001. She offers medical illustration and graphic design services to a variety of clients in the medical arena.

The work of Frank Netter has been a valuable part of Kristen's medical library throughout her 20-year career. That said, she is honored to continue the Netter tradition by producing work authentic to his distinctive style.

About the Author

Michael B. Gotway, MD, is a cardiopulmonary radiologist at the Mayo Clinic in Scottsdale, Arizona. Dr. Gotway completed his medical school training at the University of Illinois at Chicago, after which he performed his diagnostic radiology residency training at the University of California, San Francisco (UCSF), where he was presented with the Elmer Ng, MD award as outstanding diagnostic radiology resident. Dr. Gotway subsequently performed his cardiopulmonary imaging fellowship at UCSF, after which he joined the faculty at UCSF in cardiopulmonary imaging, based at San Francisco General Hospital (SFGH). Dr. Gotway was presented with the Outstanding Teacher Award by the Department of Medicine, section of Pulmonary and Critical Care Medicine, in 1999 and the Hideyo Minagi Outstanding Teacher Award by the UCSF Diagnostic Radiology Residency Program in 2002. Dr. Gotway held the position of Radiology Residency Program Director at UCSF from 2001 to 2005, as well as the Body Imaging Fellowship Director at SFGH from 2002 to 2004. From 2004 to 2005, Dr. Gotway was acting Vice-Chair for the Department of Radiology at UCSF, as well as the acting Chief of Radiology at SFGH. Before joining the Mayo Clinic, Dr. Gotway was a radiologist partner at Scottsdale Medical Imaging, Ltd, an affiliate of Southwest Diagnostic Imaging, from 2005 to 2012.

Preface

Thoracic computed tomography (CT) is a commonly performed procedure and an integral part of modern medical practice. Like most CT imaging, thoracic CT is performed and interpreted in the *transverse* plane. The transverse plane, or as more commonly referred to in daily practice, the *axial* plane, is perpendicular to the long axis of the body, dividing the body into cranial and caudal portions. When viewing axial supine CT sections, by convention, the patient's right side is on the viewer's left, with anterior structures at the "top" of the image. With multislice CT, serial, contiguous axial sections are acquired as a volume and can be displayed at various slice thicknesses, depending on the desired spatial resolution. The image data are commonly presented as a cephalocaudad "stack" of images that the user can actively scroll through. This display convention has been adopted in this volume. In clinical practice, anatomy is often tracked from image to image when scrolling in a cephalocaudad direction, allowing the reader to develop a three-dimensional impression of the structure of interest. The user is encouraged to adopt this approach when reviewing the thoracic and cardiac images to foster a three-dimensional understanding of cardiothoracic anatomy.

The thoracic CT images in this volume are displayed in both "soft tissue" and "lung" windows. The term "windowing" refers to manipulation of the display parameters (window width and window level) whereby the user changes the grayscale of an image to facilitate visualization of various anatomical structures. In the thoracic CT section of this volume, at each level, two images are shown: one displayed using a lung window, the other displayed using a soft-tissue window. These displays are created from the same source image; the display is merely changed to a lung window to optimize visualization of lung anatomy and to a soft tissue window to highlight mediastinal anatomy. In practice, several different window width and level settings are employed during review of CT images, each tailored to show the anatomy of interest to advantage.

Cardiac computed tomographic angiography (CTA) is a relatively recent development in the continual improvement of CT technology. Cardiac CTA is performed during the bolus administration of intravenous contrast material and during a breath hold, and the scan is performed in conjunction with electrocardiographic (ECG) gating to control for cardiac motion. CTA examinations performed using retrospective ECG gating allow for the reconstruction of CT data at various time points during the cardiac cycle. Because CT is sensitive to motion, and even minimal motion may compromise the quality of a cardiac CTA examination, ECG gating is an integral part of the performance of cardiac CTA. Images obtained when heart motion is relatively minimized, typically during diastole when the heart is undergoing isovolumic relaxation, provide relatively motion-free images for interpretation.

A typical cardiac CTA examination is performed in the axial plane and contains hundreds of images. The interpreter reviews these images and actively interacts with the data, creating various images that highlight particular aspects of cardiac anatomy or pathology. For cardiac imaging, the axial plane is not the only imaging plane, or even the primary imaging plane, used for interpretation. Rather, other imaging planes are created with reference to the axis of the heart: *2-chamber views (vertical long axis), 4-chamber views (horizontal long axis), and short axis* views of the heart are commonly employed. These planes are easily constructed from the axial data, and several examples of these imaging planes are presented at the end of the cardiac CTA section and in the cardiac MRI section. The axial plane is used for anatomical illustration in the cardiac CTA plates because it is the plane in which the data are acquired and an appreciation of non-axial cardiac anatomy is facilitated by first gaining an understanding of cardiovascular anatomy in the axial plane. After axial anatomy is understood, using a dedicated workstation to actively manipulate the data and visualize cardiac anatomy in various projections is the best method to gain a firm understanding of cardiovascular anatomy.

Note that right ventricular anatomy is not particularly well illustrated in the cardiac CTA study shown in these plates. This is because cardiac CTA examinations are often performed with injection of saline following the injection of iodinated intravenous contrast media, effectively "washing contrast" from the right cardiac chambers. This is done because dense intravenous

contrast within the right heart chambers may create artifacts that impair visualization of important cardiovascular structures, particularly the right coronary artery. The reader is referred to the magnetic resonance imaging plates for details regarding right atrial and ventricular anatomy.

The number of images acquired in a typical cardiac CTA examination can be large. Because of space limitations, all the images acquired in the examination used for these plates cannot be shown, but relevant sections (roughly every sixth image from the actual examination) are presented to illustrate normal cardiovascular anatomy.

The information displayed in the cardiac anatomy plates is primarily geared toward cardiovascular anatomy. Some non–cardiovascular structures are illustrated because they are well seen during cardiac CTA examinations and those interpreting these studies must possess a detailed knowledge of non–cardiovascular thoracic anatomy because pathological conditions affecting non–cardiovascular structures are commonly encountered at cardiac CTA examinations. The reader is referred to the thoracic anatomy plates for a more detailed review of non–cardiovascular anatomy, particularly pulmonary anatomy.

Magnetic resonance imaging (MRI, or MR) is a technology that also produces cross-sectional images of thoracic and cardiovascular structures but operates using a completely different physical basis than CT imaging—MRI does not employ ionizing radiation to generate image data. MR can provide exquisite visualization of mediastinal anatomy, but the MR images in this volume are restricted to cardiac anatomy because of space limitations. MR imaging can be performed using a wide variety of techniques, each of which has specific benefits and limitations. In this volume, basic "black-blood" and "white-blood" imaging sequences are shown side by side. Although the anatomy shown in image sequence pairs coincides very closely, unlike the process of windowing with CT images, creation of these images does require separate scans, so very slight differences in the anatomical details of these image pairs may be evident to the astute observer. Although white-blood imaging depicts flowing blood as bright, this imaging sequence does not require the use of intravenous contrast.

MR imaging can be acquired in any plane. As with cardiac CTA, axial data are often obtained, but the cardiac imaging planes constitute the primary imaging planes used for clinical interpretation. The MRI plates in this volume are obtained in the axial plane and supplemented with cardiac imaging planes similar to the cardiac CTA plates.

Finally, several plates illustrating minor anatomical variations are shown. These variations include often incidentally detected tracheobronchial, fissure, and venous anomalies. In addition, the axial data chosen for the MRI plates show a minor vascular aberrancy—the aberrant right subclavian artery. The anatomical variations displayed in this volume generally carry little clinical significance. However, it is anticipated that the display of such variations will enhance the appreciation of the "normal" anatomy shown in the other plates while highlighting the power of imaging to demonstrate human anatomy.

Michael B. Gotway, MD

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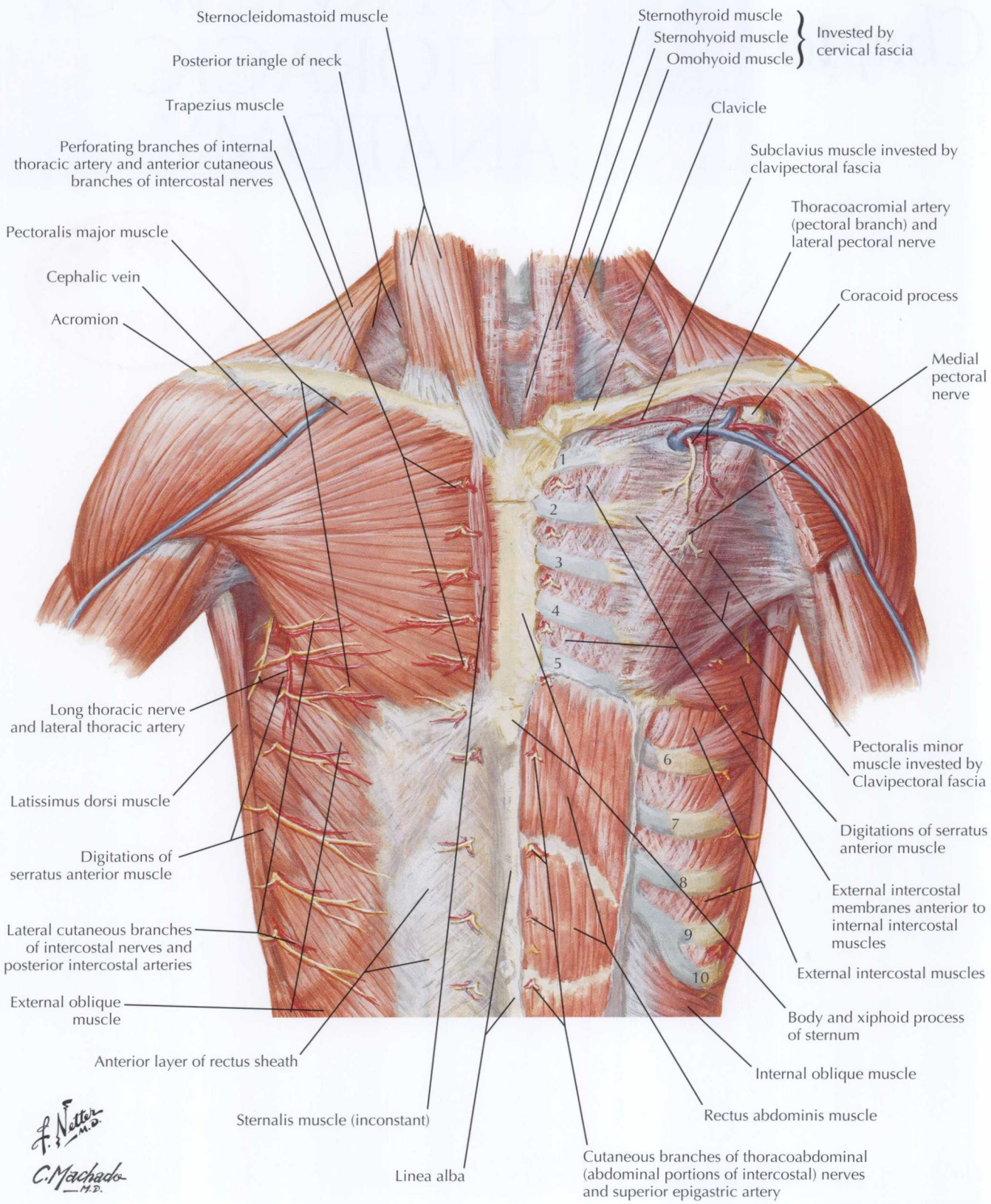
PART 1 THORACIC ANATOMY

Chapter 1 OVERVIEW OF THORACIC ANATOMY



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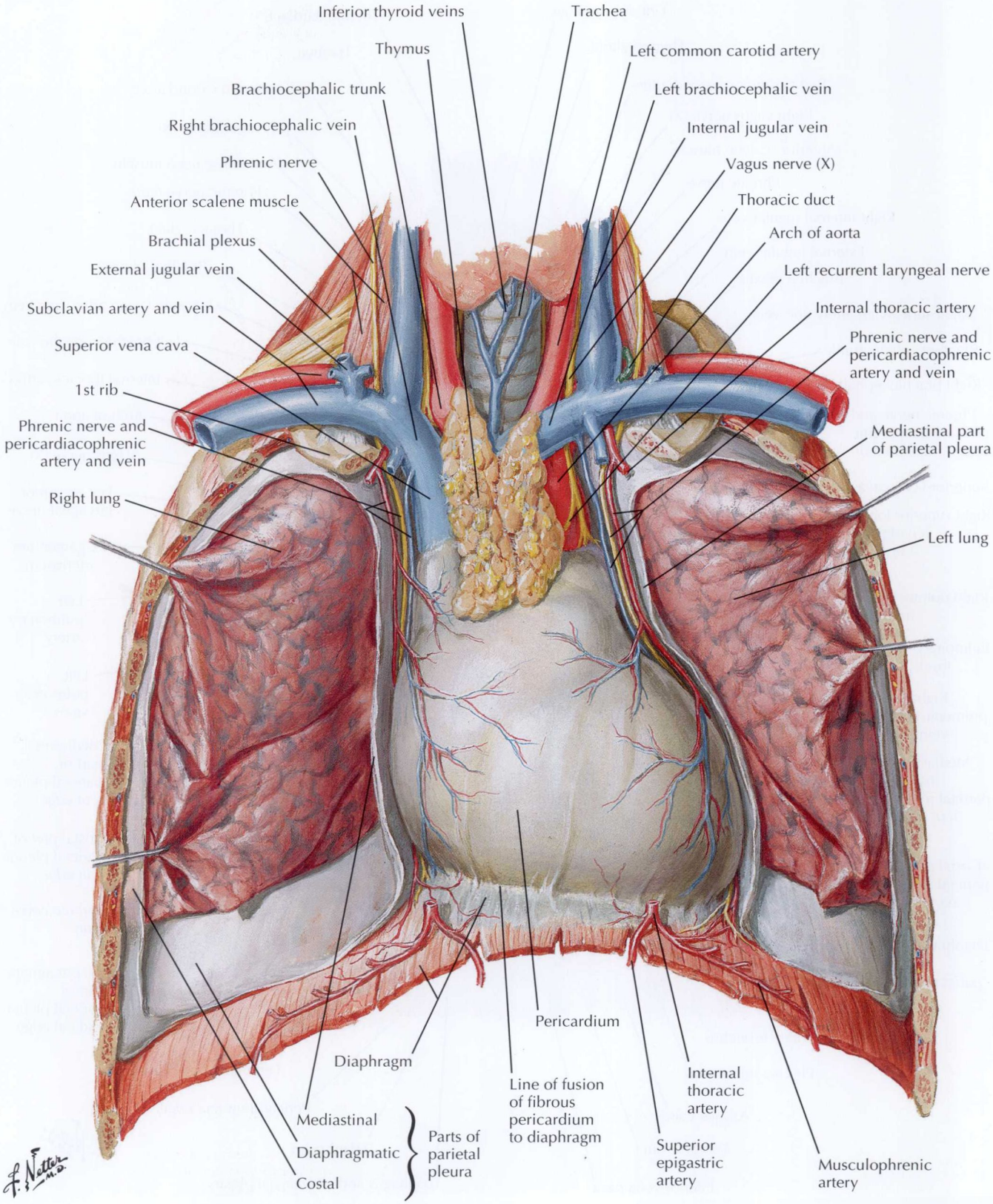
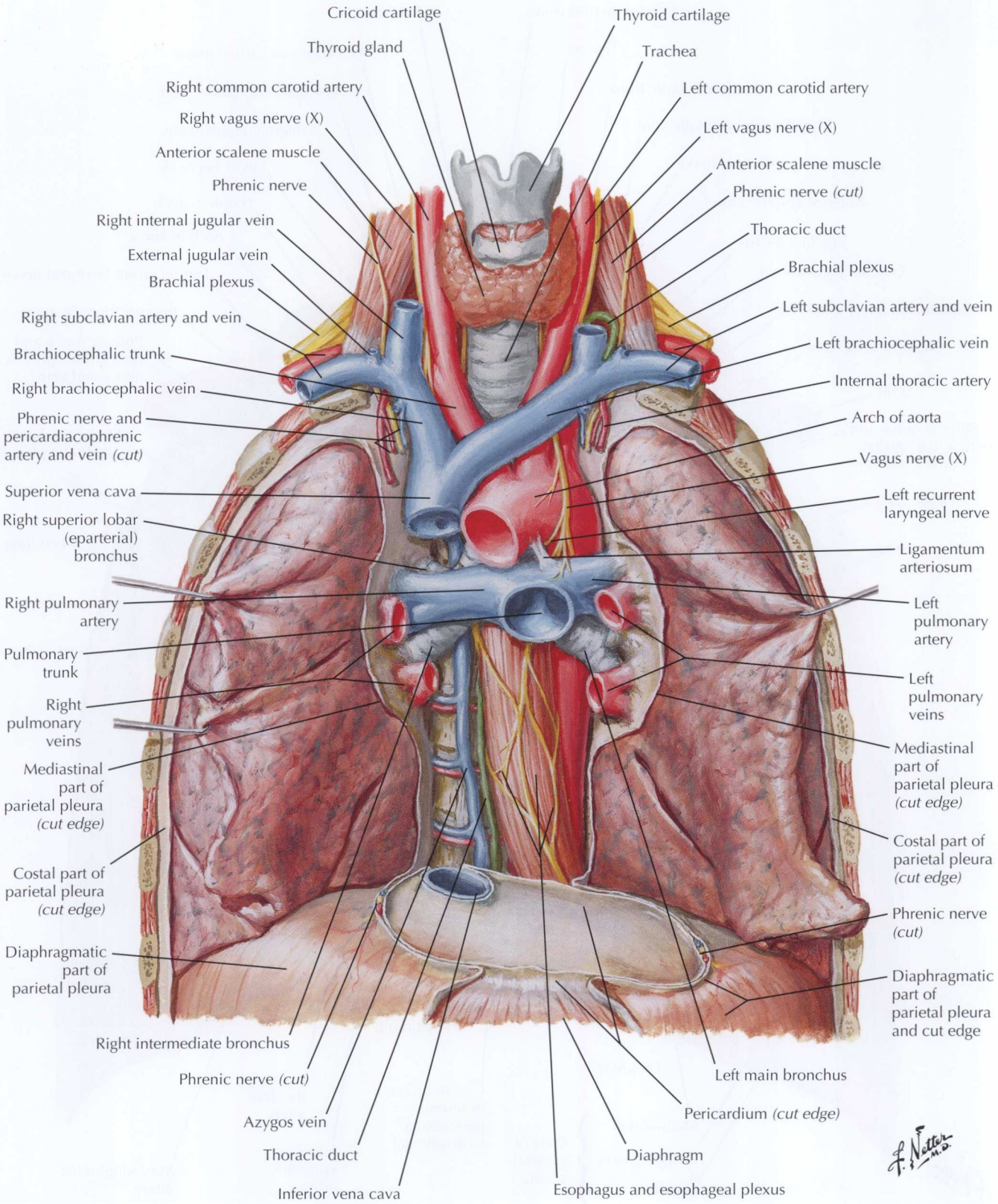
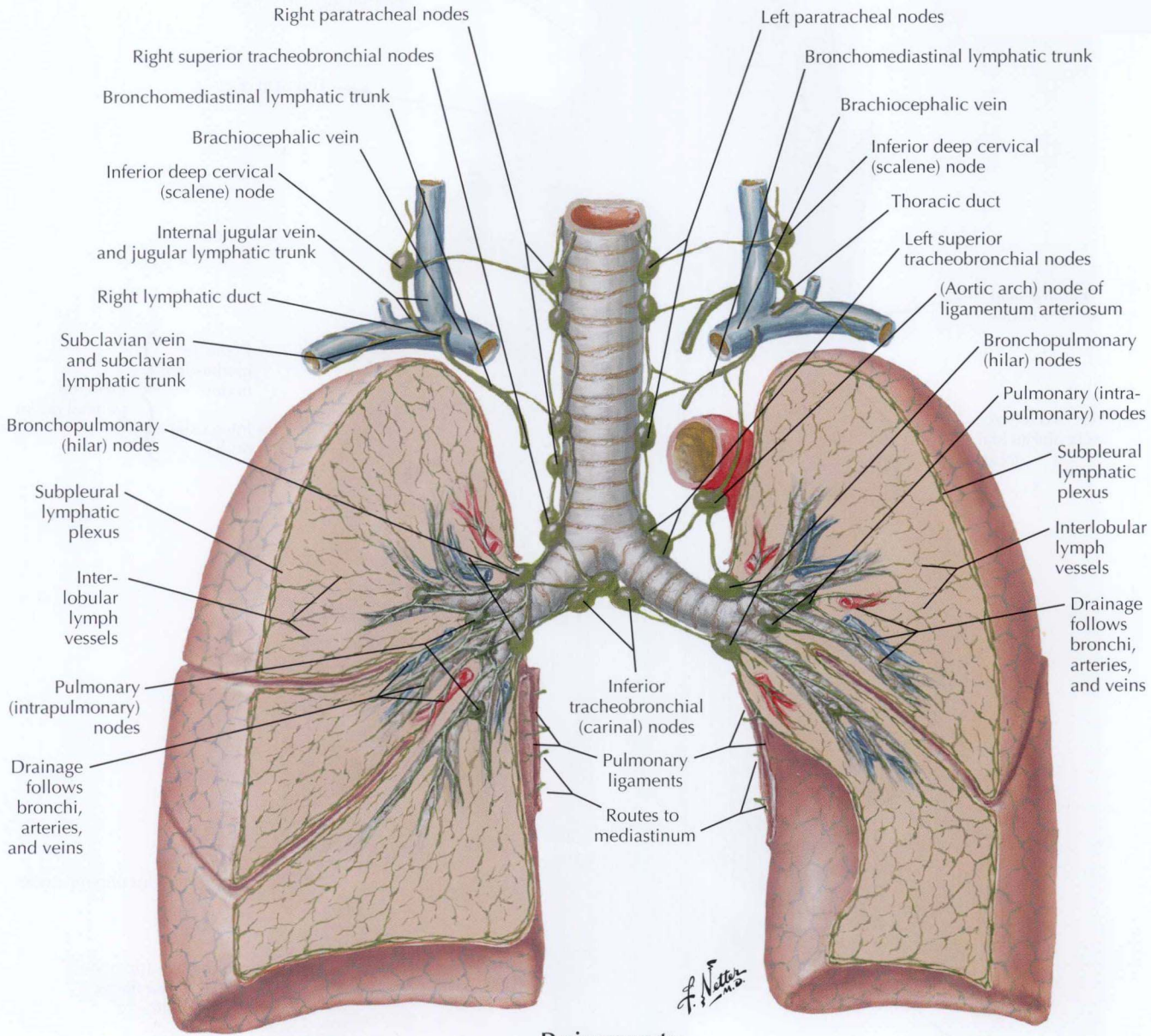
C. Machado M.D.


Inferior thyroid veins
Trachea
Thymus
Left common carotid artery
Brachiocephalic trunk
Left brachiocephalic vein
Right brachiocephalic vein
Internal jugular vein
Phrenic nerve
Vagus nerve (X)
Anterior scalene muscle
Thoracic duct
Brachial plexus
Arch of aorta
External jugular vein
Left recurrent laryngeal nerve
Subclavian artery and vein
Internal thoracic artery
Superior vena cava
Phrenic nerve and pericardiacophrenic artery and vein
1st rib
Phrenic nerve and pericardiacophrenic artery and vein
Mediastinal part of parietal pleura
Right lung
Left lung
Pericardium
Diaphragm
Line of fusion of fibrous pericardium to diaphragm
Internal thoracic artery
Mediastinal
Diaphragmatic
Costal
Parts of parietal pleura
Superior epigastric artery
Musculophrenic artery


Cricoid cartilage
Thyroid cartilage
Thyroid gland
Trachea
Right common carotid artery
Left common carotid artery
Right vagus nerve (X)
Left vagus nerve (X)
Anterior scalene muscle
Anterior scalene muscle
Phrenic nerve
Phrenic nerve (cut)
Right internal jugular vein
Thoracic duct
External jugular vein
Brachial plexus
Brachial plexus
Right subclavian artery and vein
Left subclavian artery and vein
Brachiocephalic trunk
Left brachiocephalic vein
Right brachiocephalic vein
Internal thoracic artery
Phrenic nerve and pericardiacophrenic artery and vein (cut)
Arch of aorta
Vagus nerve (X)
Superior vena cava
Left recurrent laryngeal nerve
Right superior lobar (eparterial) bronchus
Ligamentum arteriosum
Right pulmonary artery
Left pulmonary artery
Pulmonary trunk
Left pulmonary veins
Right pulmonary veins
Mediastinal part of parietal pleura (cut edge)
Mediastinal part of parietal pleura (cut edge)
Costal part of parietal pleura (cut edge)
Costal part of parietal pleura (cut edge)
Phrenic nerve (cut)
Diaphragmatic part of parietal pleura
Diaphragmatic part of parietal pleura and cut edge
Right intermediate bronchus
Left main bronchus
Phrenic nerve (cut)
Pericardium (cut edge)
Azygos vein
Thoracic duct
Diaphragm
Inferior vena cava
Esophagus and esophageal plexus



Drainage routes

Right lung: All lobes drain to pulmonary and bronchopulmonary (hilar) nodes, then to inferior tracheobronchial (carinal) nodes, right superior tracheobronchial nodes, and right paratracheal nodes on the way to the brachiocephalic vein via the bronchomediastinal lymphatic trunk and/or inferior deep cervical (scalene) node.

Left lung: The superior lobe drains to pulmonary and bronchopulmonary (hilar) nodes, inferior tracheobronchial (carinal) nodes, left superior tracheobronchial nodes, left paratracheal nodes and/or (aortic arch) node of ligamentum arteriosum, then to the brachiocephalic vein via the left bronchomediastinal trunk and thoracic duct. The left inferior lobe also drains to the pulmonary and bronchopulmonary (hilar) nodes and to inferior tracheobronchial (carinal) nodes, but then mostly to right superior tracheobronchial nodes, where it follows the same route as lymph from the right lung.

Lymph Vessels and Nodes of Esophagus