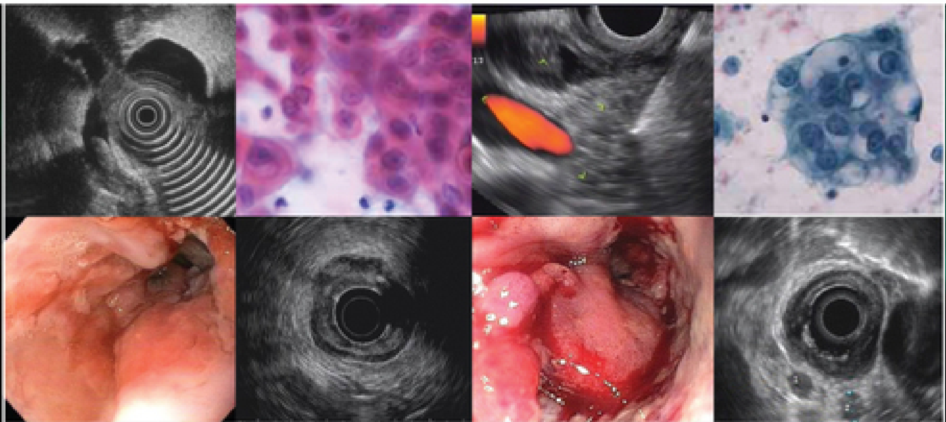
Atlas of Endoscopic Ultrasonography



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Companion DVD-ROM

This book is accompanied by a companion DVD with:

- A database of videos showing procedures described in the book.
- A search feature.
- All videos are referenced in the text at the end of each chapter.

All figures from the book are available for downloading at:
www.wiley.com/go/gress/ultrasonography.

We dedicate this to our families whose support and love allowed us to create this atlas.

Atlas of Endoscopic Ultrasonography

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Preface

Learning to perform and interpret endoscopic ultrasound (EUS) requires both didactic learning and repetitive exposure to images. We presented detailed aspects of the didactic part of learning in the Gress and Savides textbook *Endoscopic Ultrasonography*. The purpose of this atlas is to allow aspiring endosonographers to visualize numerous examples of images and videos as they improve their pattern recognition of pathologic conditions. Additionally, expert authors have been asked to write a brief, less than 1000 words narrative without references, about the important concepts related to their topics.

This atlas will be of interest not only to those learning EUS, but also those who already perform EUS and want to quickly update their daily use of EUS in terms of diagnosis and therapy. Additionally, the images and videos are in a form which can be easily downloaded from the accompanying DVD in order to give presentations to others.

We are lucky to have added two expert teachers of endosonography, Brenna Bounds and John Deutsch. They bring expertise in EUS video training to the project, as well as contributing significantly from their collections. Without them, this project would not have been possible.

Our contributors are either the "first-generation" pioneers of endosonograpy or "second-generation" protégés of those pioneers. Their collective experience in applying endoscopic ultrasonography in the management of gastrointestinal diseases is unsurpassed. A tremendous amount of effort on the part of each individual author has led to this new atlas. We are deeply grateful to them for their outstanding collaboration.

Frank G. Gress
Thomas J. Savides

1

Normal EUS Anatomy

1 Normal Human Anatomy

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Introduction

The Visible Human Project at the University of Colorado has generated large volumes of human anatomy data. The original information is captured by slowly abrading away frozen human cadavers in a transaxial manner and capturing the anatomy by digital imaging. The digital data is compiled and then over the years is manipulated by scientists at the University's Center for Human Simulation to allow access to identified cross sections in any plane as well as to models which can be lifted from the data set. Details regarding the Visible Human Project and its applications to gastroenterology and endosonography have been previously described.

This atlas is fortunate to be able to use the interactive anatomy resources developed by Vic Spitzer, Karl Reinig, David Rubenstein, and others to create movies that help explain what takes place during endoscopic ultrasound (EUS) evaluations. Since EUS is a "real-time" examination, it seems reasonable to present this section primarily as "real-time" videos. The videos can be viewed over and over, allowing endosonographers to look not only at the highlighted structures, but also at structures they might visualize during EUS that are not specifically identified on the selected video.

This chapter uses the terms "radial array orientation" to describe planar anatomy which would be found perpendicular to a line going through the digestive tract (as would be generated by a radial array echoendoscope, Figure 1.1) and "linear array orientation" for planar anatomy generated parallel to a line going through the digestive tract (as would be generated by a linear array echoendoscope, Figure 1.2).

Normal EUS anatomy from the esophagus

Radial array orientation (Video 1.1)

Video 1.1 starts with Visible Human Models of the left atrium (purple), trachea and bronchi (light blue), aorta and pulmonary arteries (red), vena cava (dark blue), and the esophagus (brown). A plane is shown passing through the esophagus. This plane contains the transaxial cross-sectional anatomy images which then follow, starting in the oropharynx and going caudally. The upper esophageal sphincter (UES) is identified. As the images proceed distally, the trachea and esophagus can be followed to a point where the brachiocephalicn left carotid and left subclavian arteries are evident just above the aortic arch. Below the aortic arch is the aortopulmonary window. The azygous arch can be seen exiting the superior vena cava (SVC). This occurs just above the tracheal bifurcation. The esophagus, labeled as "E" is surrounded by the descending aorta, the vertebrae, and the trachea. The thoracic duct (not labeled) is visible between the aorta and vertebrae, inferior to the esophagus. Going distally, the pulmonary artery becomes prominent. The region between the right mainstem bronchus (RMB) and left mainstem bronchus (LMB) is the subcarinal space. The video progresses to a level where the left artrium surrounds the superior aspect of the esophagus and then the video ends as the esophagus passes the gastroesophageal junction.

An image plane cross-section of taken from a radial array orientation at the level of the subcarinal space is shown (Figure 1.3).

Linear array orientation (Video 1.2)

Video 1.2 starts with the same models as above (The left atrium [purple], trachea and bronchi [light blue], aorta and

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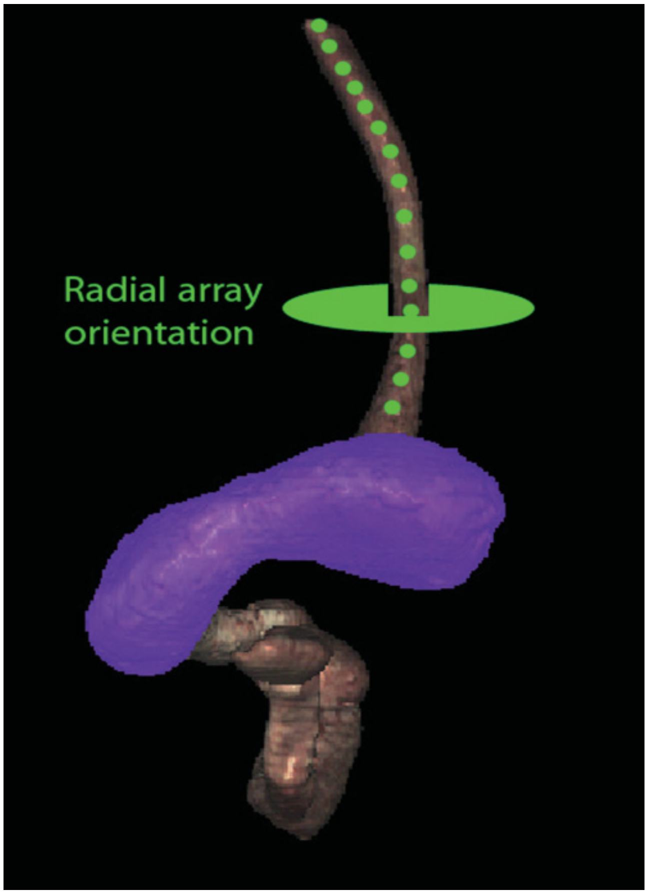

Figure 1.1 Visible Human Model of esophagus, stomach, and duodenum. The green circle shows a plane perpendicular to the axis and is similar to a plane developed during radial array endosonography.

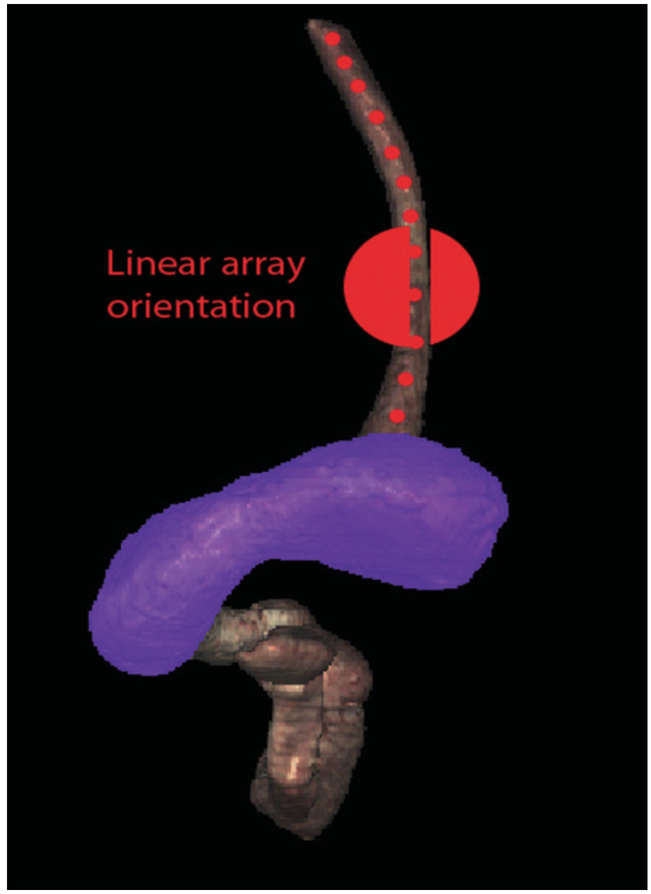

Figure 1.2 Visible Human Model of esophagus, stomach, and duodenum. The red circle shows a plane parallel to the axis and is similar to a plane developed during linear array endosonography.

pulmonary arteries [red], vena cava [dark blue], and the esophagus [brown]). The plane shows potential ways that cross-sectional anatomy can be generated. The video then shows a sagittal image with the descending aorta inferior to the esophagus, much as what is done during linear array EUS. In this orientation the pulmonary artery (PA) and left atrium are superior. The image plane is rotated to bring the left atrium and pulmonary artery to the inferior side of the esophagus. The models are then shown again, and the plane is moved in the caudal and cephalad directions, much as during EUS.

Normal EUS anatomy from the stomach

Radial array orientation (Video 1.3)

Endoscopic ultrasound of the stomach differs from EUS at other sites since the stomach does not constrain the endoscope tightly. It is important to follow anatomical structures (such as in a station approach) to avoid getting lost.

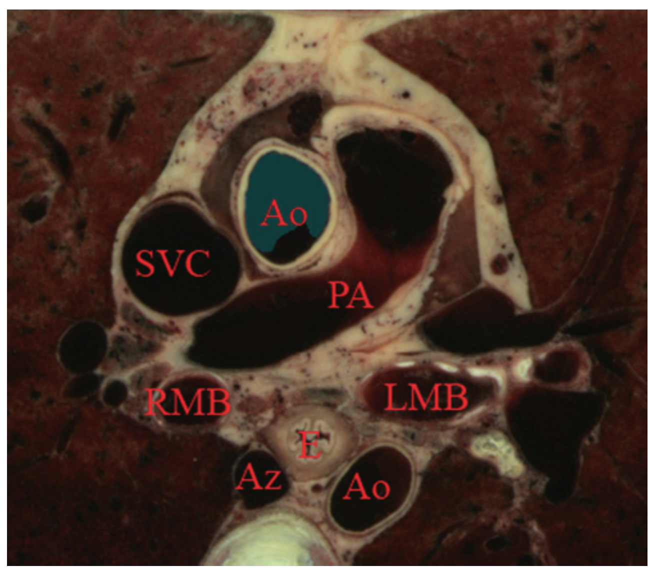

Figure 1.3 Transaxial cross-section of digital anatomy taken at the level of the subcarinal space (Ao = aorta [both ascending, superior in the image, and descending, inferior in the image, are shown]; Az = azygos vein; PA = pulmonary artery; RMB and LMB = right and left main stem bronchi; SVC = superior vena cava).

The video shows models of the stomach, esophagus, duodenum, gallbladder, pancreas (brown), the aorta, splenic artery, hepatic artery and left gastric artery (red), adrenal glands (pink), and splenic, superior mesenteric veins (dark blue) as viewed from behind. A plane is passed that is similar to the image plane generated during radial array EUS. The resultant cross-sectional anatomy starts at the level of the gastroesophageal junction, with the aorta and inferior vena cava (IVC) labeled. The aorta (which is collapsed) is followed, which brings the pancreas and left adrenal gland into view. The first artery that comes off the aorta in the abdomen is the celiac artery. There is a trifurcation into the splenic, hepatic, and left gastric arteries (LGA), although the LGA is generally smaller and difficult to see. It is shown in the video at the "x" just before the bifurcation into the celiac and hepatic arteries as identified.

The superior mesenteric artery (SMA) comes off the aorta just distal to the celiac artery. Various endoscope maneuvers can be used to bring the portal confluence into view, and then the splenic vein can be used as a guide to visualize the pancreas body, left adrenal, kidney, and spleen. The diaphragm can be easily imaged between the kidney and the vertebrae.

Linear array orientation (Video 1.4)

The linear array exam also follows the aorta to the stomach, but, as shown Video 1.4, the image plane across the pancreas is generally obtained through a sweeping motion. The first major gastric landmark is the origin of the celiac artery and SMA from the aorta (Figure 1.4). The superior mesenteric vein (SMV), portal vein, and splenic vein can be used as guides to go back and forth across the pancreas and in the process, the left adrenal, kidney, and spleen can be seen. The splenic artery runs roughly parallel to the splenic vein, but is generally tortuous.

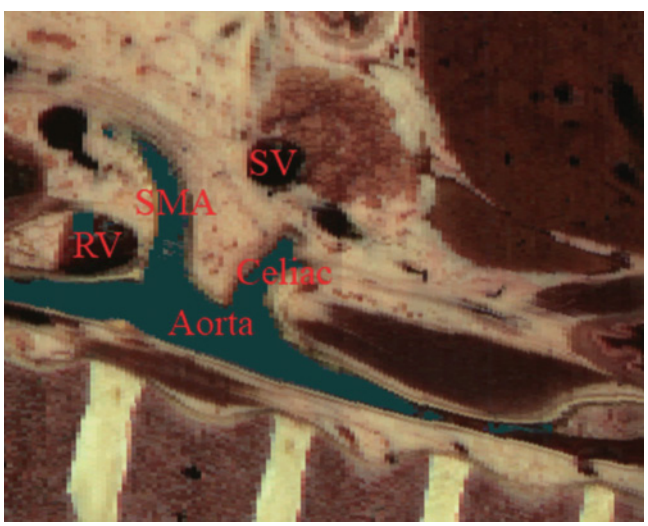

Figure 1.4 Sagital cross-section of digital anatomy at the level of the gastroesophageal junction, similar to a view seen during linear array endoscopic ultrasound (EUS). The celiac and superior mesenteric arteries (SMA) are shown at their insertion into the aorta. The renal vein (RV) is shown adjacent to the SMA and the splenic vein is shown adjacent to the pancreas.

Normal EUS anatomy from the duodenum

Radial array orientation (Video 1.5)

The radial array EUS examination through the duodenum follows a constrained path, but the endoscope can be rotated to put various structures into the inferior aspect of the image plane, as shown in the models of the duodenum, pancreas (brown), portal and superior mesenteric veins (blue), aorta (red), and SMA (silver). There are many structures of interest in a rather small area, and most of the images obtained are from the posterior view, with the liver to the right and the pancreas to the left of the image screen. After leaving the pylorus, the pancreas can be oriented with the tail pointed either to the left or inferiorly, and the splenic vein runs in the same direction as the pancreas. Going through the duodenal bulb, the gastroduodenal artery (GDA) often appears. Without Doppler, the GDA can be confused with the common bile duct (CBD) since these structures are nearly parallel in orientation and are very close to each other. As the apex of the duodenal bulb is reached, the image plane captures a longitudinal view of the CBD and the portal vein. As the descending duodenum is reached, the bile duct is seen in cross-section and the inferior vena cava (IVC) comes into view. As the third part of the duodenum is reached, the image plane rotates in such a way as to give a longitudinal cut through the IVC and then passes underneath the junction of the SMA with the aorta. Branches of the SMV can be found and the renal vein is visible in the "armpit" formed at the insertion of the SMA into the aorta. A special area is then highlighted in Video 1.5. Models show how the gastroduodenal artery and the hepatic artery (in red) relate to the CBD (in orange).

Figure 1.5 shows a model with an image plane and Figure 1.6 shows the resultant planar anatomy, which forms the stack sign – a phenomenon in which the portal vein, CBD, and main pancreatic duct are captured in the same field.

Linear array orientation (Video 1.6)

The linear array exam of the duodenum is an excellent way to see the CBD and pancreatic head. The anatomy is difficult to understand since the endoscope image is tipped into the C-sweep of the duodenum, and then the image plane is swept in various angles, resulting in a cross-sectioning of the CBD and pancreatic duct (PD). The image planes employed can be appreciated from observing the models in the video. The cross-sections obtained can be positioned to first give a

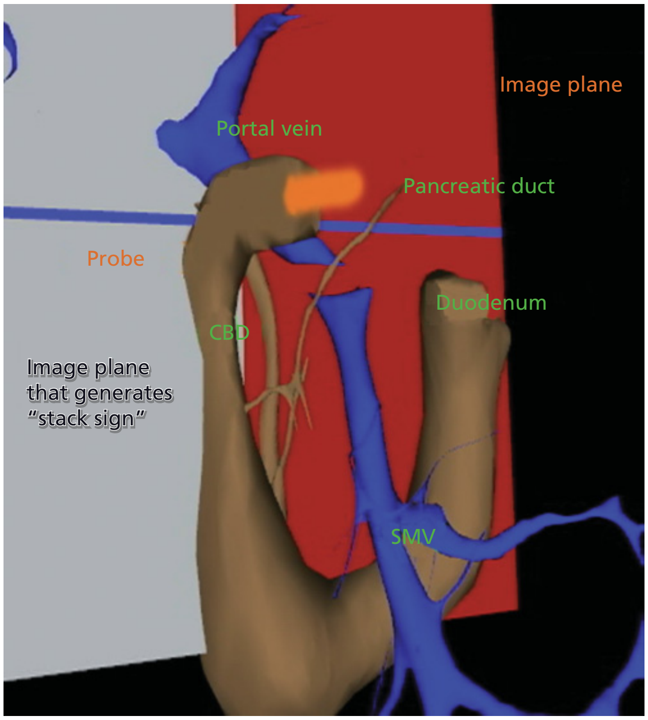

Figure 1.5 Visible Human Model of an image plane that is in the location in which radial array endoscopic ultrasound (EUS) generates the "stack sign", in which the portal vein, common bile duct (CBD), and pancreatic duct are in the same field. A probe in orange is shown going into the proximal duodenum. The superior mesenteric vein (SMV) is also shown.

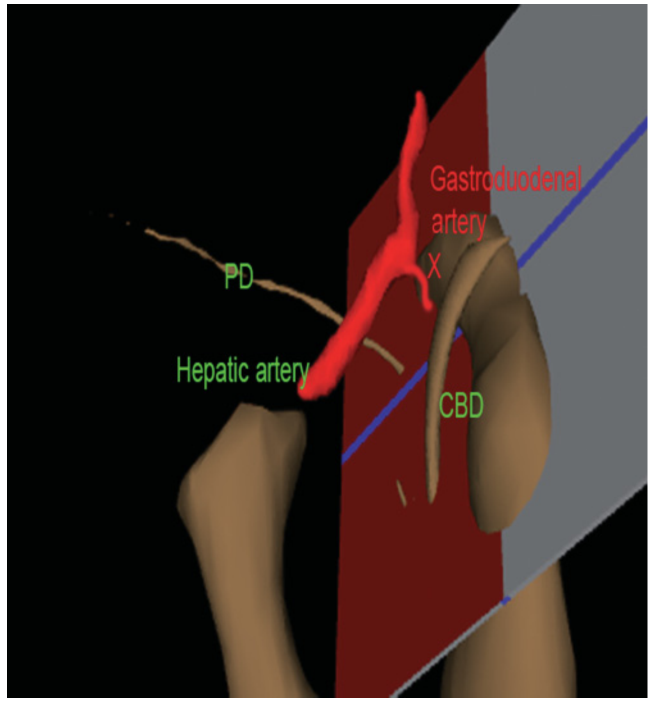

Figure 1.7 Visible Human Model with a plane that is in a location similar to what can be generated during linear array endoscopic ultrasound (EUS), showing the relative position of the gastroduodenal artery, pancreatic duct (PD), hepatic artery, and common bile duct (CBD).

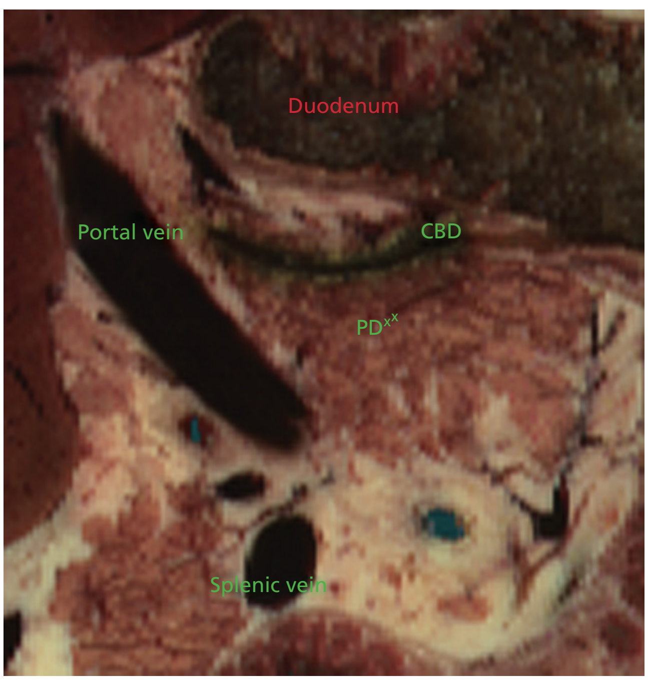

Figure 1.6 The cross-sectional anatomy within the plane shown in Figure 1.3. The common bile duct (CBD), pancreatic duct (PD), and portal vein are all in the same field ("stack sign").

longitudinal view of the CBD and both longitudinal views and cross-sections of the portal vein and SMV.

As seen in the first part of Video 1.6, if the endoscope is in the second part of the duodenum, the bile duct goes to the ampulla away from the transducer and the liver is towards the transducer. If the endoscope is in the duodenal bulb, as shown in the second part of the video, the liver is away from the transducer.

The GDA drapes over the portal vein and can be found most readily using Doppler. Figure 1.7 shows a model and Figure 1.8 the resultant cross-section where the GDA can be found.

Normal EUS anatomy from the rectum

Radial array orientation, male (Video 1.7)

Video 1.7 shows models of various male pelvic structures, starting with the rectum and sigmoid colon, the aorta, and the iliac arteries with internal and external branches. The SMA is included to show the anterior direction of the models. The prostate, bladder, coccyx, and sacrum are added sequentially. A second set of models is then shown which contains the rectum, sigmoid colon prostate, bladder, coccyx,

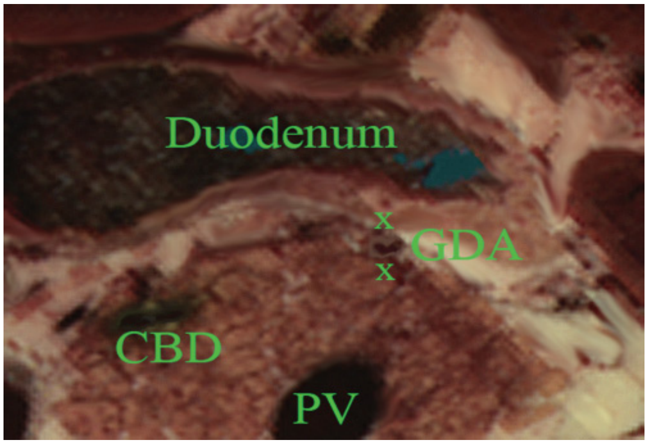

Figure 1.8 Cross-sectional anatomy generated within the plane shown in Figure 1.5. The gastroduodenal artery (GDA) and common bile duct (CBD) are shown with the pancreatic head. The portal vein (PV) is shown near the portal confluence.

sacrum external iliac arteries (red), veins (blue), as well as three-dimensional models of the internal and external anal sphincters. The sphincters and sigmoid colon are then removed.

Planar anatomy in the radial array orientation from the male rectum is then shown, starting distally and moving proximally. The anal sphincters are labeled, followed by the prostate, urethra, levator ani, and coccyx. The sacrum and seminal vesicles are then shown, followed by the right internal iliac artery.

Radial array orientation, female (Video 1.8)

Video 1.8 starts distally at the end of the anal canal. The internal and external sphincters are shown, and residual stool is present in the rectum. Moving proximally, the vagina and urethra are shown, followed by the cervix and bladder.

Linear array orientation, male (Video 1.9)

Video 1.9 starts with a sagittal plane through the pelvis with the body facing the left. The prostate, rectum anal canal, and bladder are identified. The plane is rotated, and the seminal vesicles and internal anal sphincter are labeled. The coccyx and sacrum are apparent at the start and end of the video but are unlabeled.

Linear array orientation, female (Video 1.10)

Video 1.10 starts with a sagittal plane through the pelvis with the body facing the left and slightly face down. The anal canal, rectum, uterus, and bladder are identified. Stool is present in the rectal vault. The plane is rotated, and towards the end of the video the internal anal sphincter (IS) and external anal sphincter (ES) are identified.

Vascular videos

Arterial (Video 1.11)

Video 1.11 shows models of some of the main arteries that are visulaized during endosonography. A close-up view shows the celiac artery with its branches (hepatic, splenic, and left gastric arteries). The gastroduodenal and pancreaoduodenal arteries are shown coming off the hepatic artery. The internal and external iliac arteries are then identified, followed by identification of the arteries associated with the aortic arch (left subclavian, left carotid, brachiocephalic) and the branches of the brachiocephalic (right subclavian and right carotid). Various organs are then placed in the model starting with the esophagus, then pancreas, stomach, and duodenum.

Venous (Video 1.12)

Some of the major veins visualized during endosonography are shown. At first, the vena cava and right artrium are identified, after which, the renal veins and azygos veins are added. The portal system with the portal vein, SMV, splenic vein, and inferior mesenteric vein (not labeled) are placed in blue. The systemic veins are then colored and removed. The pancreas is placed on the portal vein and its branches, showing how the head runs parallel to the SMV and the tail runs parallel to the splenic vein.

Endobronchial ultrasound anatomy (Video 1.13)

Extratracheal anatomy is similar to extraesophageal anatomy and many of the structures seen in the extratrachial spaces are the same as what is seen in the extraesophageal spaces. The endoluminal views of the trachea are oriented so that the membranous trachea is inferior and is splayed wider that the cartilaginous trachea at the level of the carina, putting the right mainstem bronchus (RMB) to the right and the left mainstem bronchus (LMB) to the left (Figure 1.9). As one goes right the bronchus immediately branches superiorly towards the right upper lobe (RUL), and continues straight as bronchus intermedius (BI) (Figure 1.10), which then branches towards the right middle lobe (RML) and right lower lobe (RLL) of the lung (Figure 1.11).

Going left from the carina, one goes down the relatively long left mainstem bronchus until it branches towards the left upper lobe (LUL) and left lower lobe (LLL) of the lung (Figure 1.12). An overview of the bronchial tree is shown in Figure 1.13.

Video 1.13 starts with the cervical trachea. All images are in a linear array orientation as endobronchial ultrasound (EBUS) is exclusively linear. The esophagus is inferior and the brachiocephalic artery and vein are superior. The video begins with rotation of the image plane. The superior part of the plane moves left and the inferior part moves right. This moves the esophagus out of view and brings the left

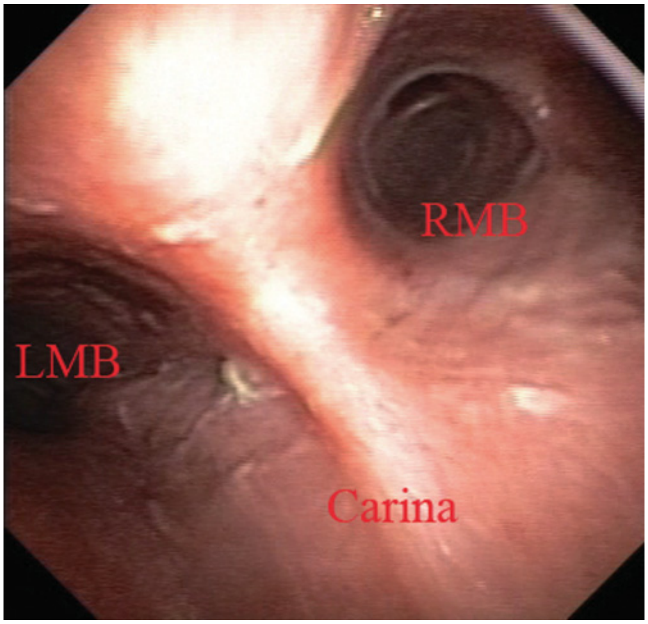

Figure 1.9 Endobronchial view of the carina, showing the right (RMB) and left (LMB) mainstem bronchi.

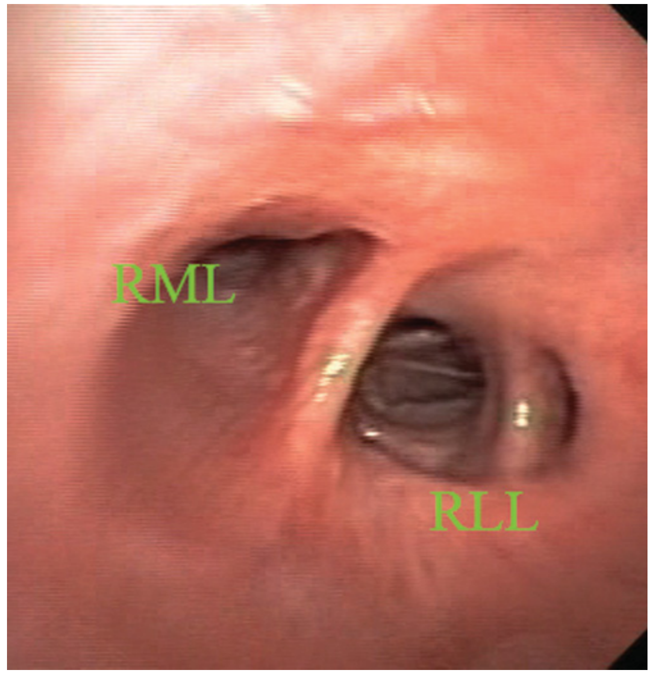

Figure 1.11 Endobronchial view of the bifurcation of the bronchus intermedius towards the right middle lobe (RML) and the right lower lobe (RLL).

Figure 1.10 Endobronchial view of the first branch of the right mainstem bronchus towards the right upper lobe (RUL) and the bronchus intermedius (BI).

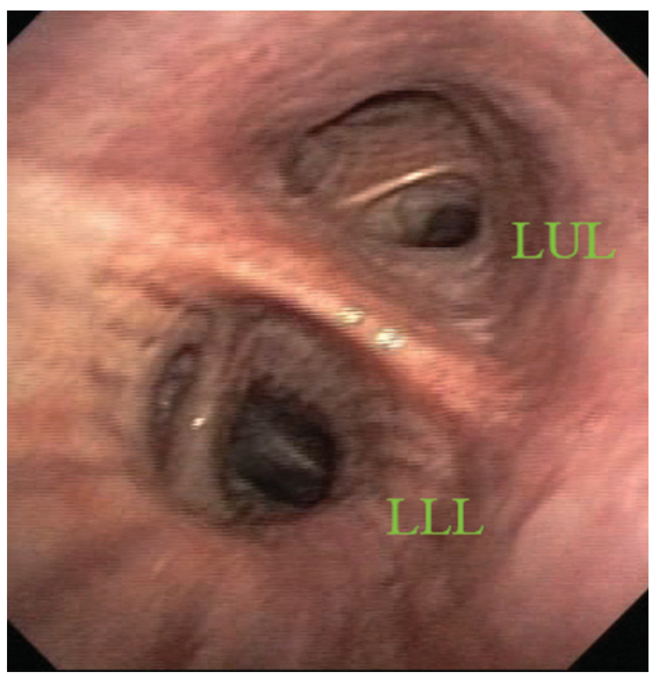

Figure 1.12 Endobronchial view of bifurcation of the left mainstem broncus towards the left upper lobe (LUL) and left lower lobe (LLL).

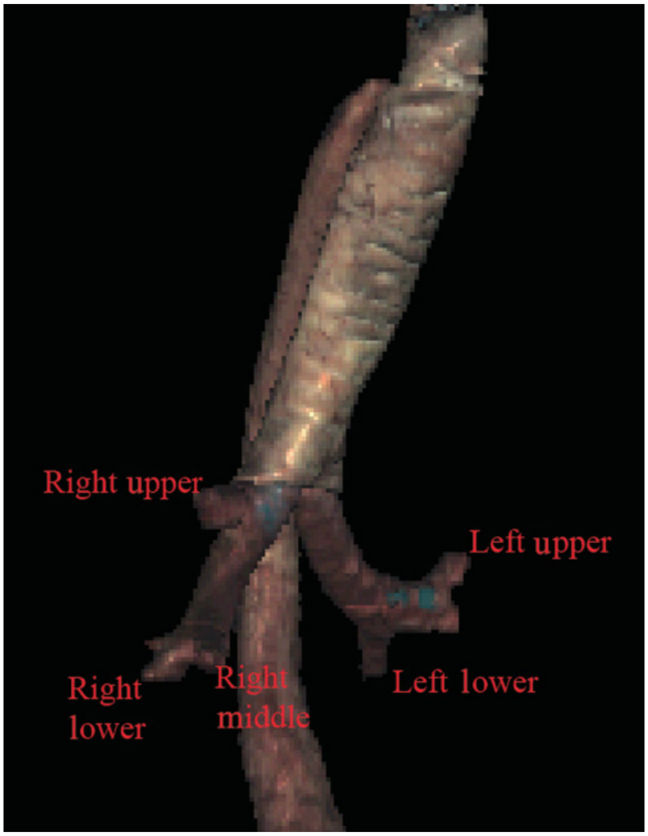

Figure 1.13 A Visible Human Model of the bronchial tree.

subclavian artery and left carotid artery into the inferior part of the image. Eventually, the esophagus is seen in the superior part of the image and, with continued motion, the esophagus again appears inferior to the trachea. At this point, the image plane moves caudally to the carina. The right pulmonary artery, brachiocephalic artery (BA), and left brachiocephalic vein (LBV) are labeled. The plane is again rotated to splay the right (RMB) and left (LMB) mainstem bronchi apart. The plane is then moved to better visualize the right mainstem bronchus, showing the branch to the right upper lobe (RUL), the azygos arch (AzArch), the bronchus intermedius (BI). This same plane shows the relation of the aortic arch (AoArch) and left pulmonary artery to the left mainstem bronchus (LMB). As the plane goes down the right mainstem bronchus/bronchus intermedius (RMB) towards its next bifurcation, the azygos arch (AzAr), right pulmonary artery (RPA), and right pulmonary vein (RPV) are shown.

The plane is brought back to the carina to visualize the left mainstem bronchus (LMB), and the azygous arch (AzAr), aortic arch (AoAr), left pulmonary artery (LPA), and vein (LPV) are identified. The branching to the left upper lobe (LUL) and left lower lobe (LLL) are shown, and the aorta (Ao) and left pulmonary artery are labeled.

Chapter video clips

Video 1.1 Esophageal-related models and cross-sectional anatomy: radial orientation.

Video 1.2 Esophageal-related models and cross-sectional anatomy: linear orientation.

Video 1.3 Gastric-related models and cross-sectional anatomy: radial orientation.

Video 1.4 Gastric-related models and cross-sectional anatomy: linear orientation.

Video 1.5 Duodenal-related models and cross-sectional anatomy: radial orientation.

Video 1.6 Duodenal-related models and cross-sectional anatomy: linear orientation.

Video 1.7 Male rectum-related models and cross-sectional anatomy: radial orientation.

Video 1.8 Male rectum-related cross-sectional anatomy: linear orientation.

Video 1.9 Female rectum-related cross-sectional anatomy: radial orientation.

Video 1.10 Female rectum-related cross-sectional anatomy: linear orientation.

Video 1.11 Arterial models.

Video 1.12 Venous models.

Video 1.13 Bronchial anatomy in a linear orientation.

2 Esophagus: Radial and Linear

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Layers of the esophageal wall

Staging the depth of involvement of tumors and the layer of origin of subepithelial masses is an important component of competency in endoscopic ultrasonography (EUS). An intimate knowledge of the normal layers of the esophageal wall is critical for this to be done accurately. The wall of the esophagus has four readily appreciable layers by EUS using standard operating frequencies (5–12 MHz). The layers are seen in concentric, alternating rings of hyper and hypoechoic structures emanating out distally from the tip of the endoscope. Starting with the layers closest to the scope tip, they are as follows:

- Interface echo between the superficial mucosa and water (hyperechoic).
- Deep mucosa (hypoechoic).
- Submucosa plus the acoustic interface between the submucosa and muscularis propria (hyperechoic).
- Muscularis propria minus the acoustic interface between the submucosa and muscularis propria (hypoechoic).

If a higher resolution frequency probe is used, greater number of layers could be visualized as detailed in Chapter 4. The esophagus lacks an obvious fifth layer as there is no serosa.

In our opinion, visualization and discernment of the layers of the esophageal wall is usually best accomplished using radial compared to linear instruments.

Figure 2.1 (a and b) shows the esophageal walls using radial and linear instruments. To help separate the layers, these images include a muscularis mucosae leiomyoma that was subsequently resected. Images show subepithelial hypoechoic lesion in echolayer II as well as in the other defined layers of the esophageal wall.

Normal radial extraesophageal anatomy

Standard examination of the esophagus and mediastinum begins with advancing the radial instrument to the gastroesophageal (GE) junction at or near the squamocolumnar junction. At this level the aorta is seen as an anechoic circular structure in the 5 o'clock position. The descending aorta is kept in this position as all radial mediastinal imaging will then correlate quite nicely with cross-sectional imaging. Other structures visible at the level of the GE junction are the inferior vena cava (IVC) seen between 7 and 9 o'clock and the liver between 6 o'clock and 12 o'clock surrounding the IVC (Figure 2.2).

As the scope is withdrawn, the vena cava moves clockwise and superiorly into the right atrium. The spine soon comes into view adjacent to the descending aorta at 6 o'clock.

Further withdrawal upward to usually around 30–35 cm reveals the anechoic chamber of the left atrium in the 12 o'clock position (Figure 2.3). With this field, relatively slight movement of the scope will reveal the mitral valve (Figure 2.4), aortic root, and the aortic valve (Figure 2.5). In the inferior portion of the field the descending aorta, the spine, the thoracic duct, and a relatively prominent azygos vein can be seen.

As the scope is withdrawn the bronchi come together at the carina. At or just proximal to this level the azygos arch (Figure 2.6) can be identified traveling superiorly and laterally into the superior vena cava. This is also the area of the aortopulmonary (AP) window at approximately 2 o'clock.

The endoscope can be pushed down from here or pulled up slightly from the position of the left atrium to reach the subcarinal space. Of interest in the subcarinal space are the right and left main-stem bronchi seen emanating out as ribbed-

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