Surgical Anatomy of Esophagus

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2.1 Introduction

The esophagus is a muscular tube of approximately 25 cm which connects the pharynx to the stomach and serves as a food passage. The greater part lies in the thorax but is has cervical and abdominal parts as well. Except for the vermiform appendix it is the narrowest part of the digestive tract. The esophagus is collapsed at rest and opens during swallowing. Its passage through the thorax with its subatmospheric pressure and the fact that it should be a highly mobile organ, due to its own peristalsis and respiratory movements, sets requirements for its construct and attachments. This chapter discusses its general features, its construction and anchoring, its important topographical relationships, vascular and nerve supply, and lymphatics.

2.2 General Features

The cervical part (3–5 cm) is posterior to the trachea and attached to it by loose connective tissue. Between it and the spine is the prevertebral layer of cervical fascia which is bilayered here, the anterior layer is named alar fascia. Therefore,

two narrow pockets with loose connective tissue exist between the esophagus and the spine [1, 2]. These pockets continue into the mediastinum. It is through the loose connective tissue, which acts as a gliding plane, that the esophagus has freedom of movement against the spine. The recurrent laryngeal nerves ascend close to the esophagus and the trachea.

The thoracic part of the esophagus (18–22 cm) traverses the superior mediastinum and the posterior mediastinum. Here it is embedded in loose connective tissue which allows for the movements which are found in the mediastinum: peristalsis of the esophagus, pulsations of the descending aorta and respiratory excursions. Among the main topographical relationships are the spine posteriorly, the trachea and the pericardium anteriorly and the descending aorta to the left.

Where the esophagus traverses the esophageal hiatus of the diaphragm it is connected to it by the phrenico-esophageal ligament. The abdominal part is short (1.5 cm) but of utmost importance. Increase of intra-abdominal pressure results in an increase of the pressure inside the stomach but the same pressure increase simultaneously compresses the abdominal part of the esophagus, thereby minimizing the risk of gastroesophageal reflux.

Inside the thoracic cavity the subatmospheric pressure keeps the elastic lungs expanded. Since it traverses the thorax the intraluminal pressure of the esophagus is lower than the pressures in the pharynx and the stomach. To prevent continuous

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suction of mucus and air from the pharynx and reflux of acid stomach contents, sphincters keep both ends of the esophagus closed except during swallowing. The upper esophageal sphincter (UES) is at the transition of the pharynx to the esophagus and is the caudalmost part of the inferior pharyngeal constrictor. This part has been named cricopharyngeus and can easily be distinguished during anatomical dissections. The lower esophageal sphincter (LES), however, is not a clear morphological entity. It is a so-called functional sphincter which means that it is a part of the esophageal musculature which can generate a high pressure and can therefore have a sphincteric action. It is at the level of passage of the esophagus through the diaphragm and continues to the gastro-esophageal junction [3]. Sphincteric action at this level is reinforced by the right crus of the diaphragm which encircles the esophagus as it traverses the diaphragm. This right crus works as an external sphincter, especially during inspiration when the intra-abdominal pressure increases.

2.3   Structure

The construction of the esophageal wall follows the general pattern of the tissue organization of the digestive tube. There are four layers, from outside inwards: adventitia (external fibrous layer), muscularis, submucosa and mucosa.

The adventitia consists of loose connective tissue which continues as the loose connective tissue elsewhere in the mediastinum. Except for the abdominal part there is no serous lining.

The muscularis consists of an outer longitudinal layer and an inner circular layer. This parallels the plan as found in more distal parts of the digestive tube. However, in the pharynx the opposite is found. An external circular layer consists of the three pharyngeal constrictors while three levators form the inner longitudinal layer. As a consequence a reorganization of muscle layers takes place at the pharynx-esophagus transition. This is the region where areas of sparse muscle exist. Killian's triangle is the area between

the thyropharyngeal part of inferior constrictor and cricopharyngeus. Zenker's hypopharyngeal diverticulum arises from here.

At the gastro-esophageal junction the longitudinal and circular muscle layers continue as similar layers in the wall of the stomach. The longitudinal layer continues along the lesser and greater curvatures of the stomach especially. Here the longitudinal muscle layer of the stomach is better developed than over its anterior and posterior surfaces. Inside the circular muscle layer of the stomach a third layer of oblique muscle fibers is present. These fibers form a U-shaped sling left to the oblique implant of the esophagus into the stomach and maintain the cardiac notch, or angle of His, between the esophagus and the greater curvature. It is not certain how much this configuration contributes to the resistance to reflux. Due to the oblique implant of the esophagus a valve-like flap (the flap-valve of Hill) is formed at the cardiac orifice, which also may help to prevent reflux.

Approximately in the upper one-third of the esophagus the muscularis is formed by striated muscle. In the middle one-third smooth muscle cells appear and intermingle with the striated muscle fibers and the lower one-third of the esophagus contains smooth muscle cells only.

The submucosa contains loose connective tissue with elastic and collagen fibers. It contains blood vessels and lymphatics, all in a plexiform arrangement.

The mucosa is thick and consists of a non-keratinized stratified squamous epithelium, a lamina propria and a muscularis mucosae. There is an abrupt transition into simple columnar epithelium at the gastro-esophageal junction. Because the line of transition is jagged it is often referred to as the Z-line. The esophageal lumen is marked by longitudinal grooves and ridges at rest. These disappear when the lumen is distended during swallowing. Gastric mucosal folds at the cardiac orifice form the so-called mucosal rosette. This may help to form a tight seal, especially for fluid and gas.

In this and the previous sections several structures and mechanisms which help to prevent gastro-esophageal reflux were discussed. To

summarize, the following factors may contribute to a greater or lesser extent. (1) The LES in the esophageal wall, (2) the right crus of the diaphragm, (3) the intra-abdominal part of the esophagus, (4) the cardiac notch and the oblique muscle fibers of the stomach, (5) the flap-valve of Hill, (6) the mucosal rosette.

2.4   Anchoring

The cranial half of the esophagus is connected to the trachea, the pleura and the alar fascia by connective tissue strands and small membranes which contain collagen and elastic fibers.

Recently it was described that the esophagus is attached to the descending aorta by the aorto-esophageal ligament (Figs. 2.1 and 2.2) [4, 5]. From this ligament a thin extension courses toward the right pleural reflection, which is the aorto-pleural ligament. The aorto-esophageal ligament contains blood vessels which run from the aorta to the esophagus. The posterior mediastinum is divided in two compartments by the aorto-esophageal and aorto-pleural ligaments. First the peri-esophageal compartment, bounded anteriorly by the pericardium, laterally by the pleura and posteriorly by the aorto-esophageal and aorto-pleural ligaments, containing the esophagus, trachea,
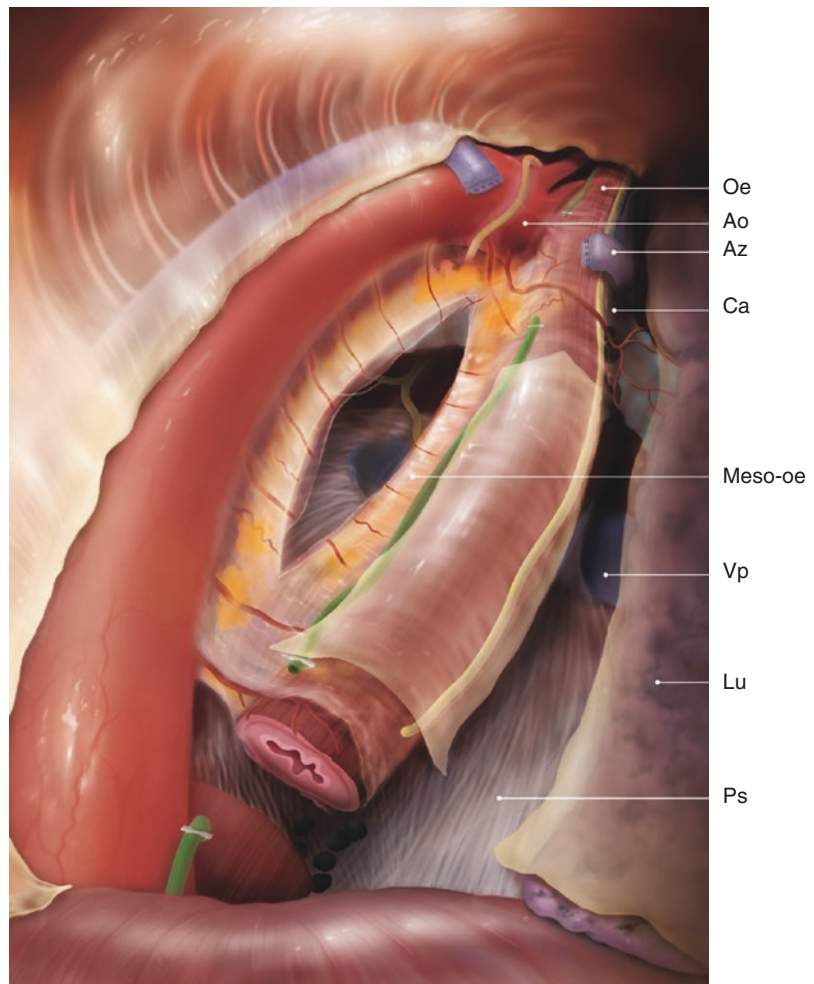

Fig. 2.1 Illustration of the aorto-esophageal ligament, previously named "meso-esophagus". It is a bilayered connective tissue layer with blood vessels coursing from the descending aorta to the esophagus. Abbreviations: *PS* pericardial sac, *Lu* right lung; *Vp* right pulmonary vein, *Ca* carina and right bronchus, *Meso-oe* meso-oesophagus, *Az* azygos vein, *Ao* aorta, *Oe* oesophagus (From [4])
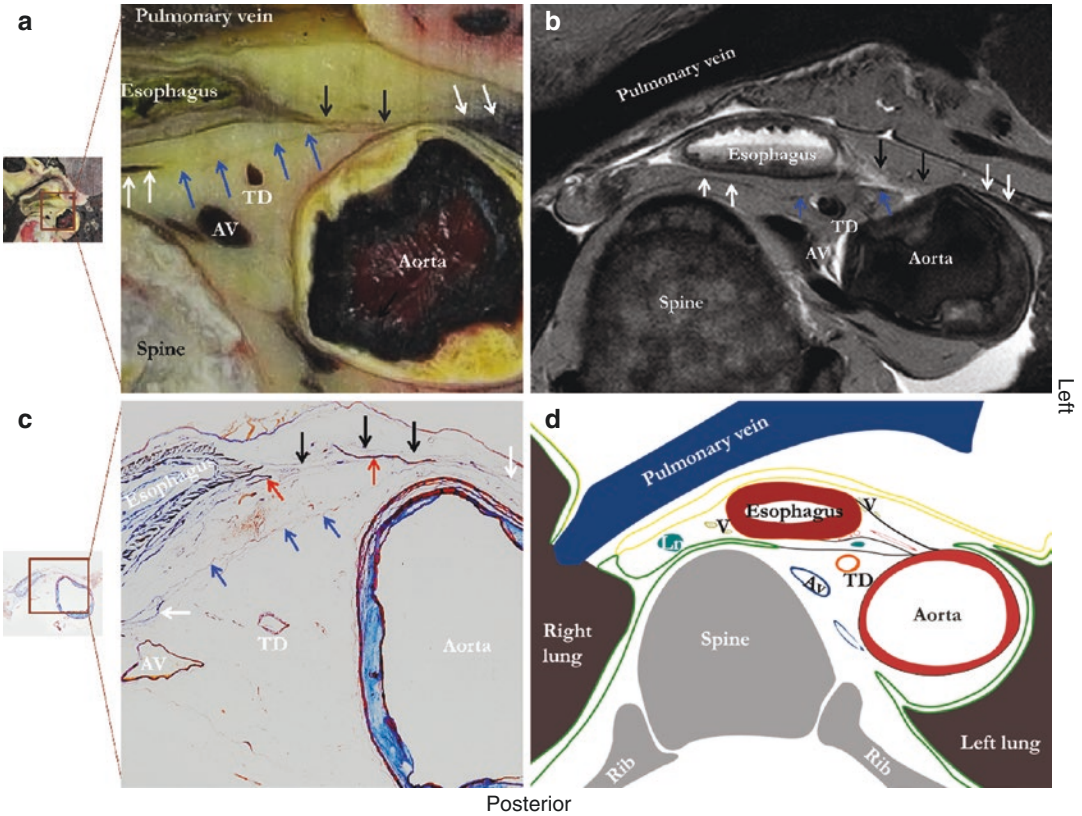
Fig. 2.2 Photograph of a transverse section of the posterior mediastinum between the diaphragm and tracheal bifurcation (**a**) with a magnetic resonance image of the same section (**b**), histology (**c**) and a schematic summary (**d**). For histology the Verhoef-Von Gieson stain was used (elastin stained *black-blue*; collagen stained *light red-pink*). The *black arrows* indicate the aorto-esophageal ligament, the *blue arrows* indicate the aorto-pleural liga-ment, the *white arrows* indicate the *right* and *left* pleural reflections and the *red arrows* indicate blood vessels. In the schematic drawing the *green line* represents the pleura, the *yellow line* represents pericardium and the *black line* the aorto-esophageal and aorto-pleural ligaments. Abbreviations: *AV* azygos vein, *TD* thoracic duct, *V* vagus nerve (From [5])

vagus nerves and carinal lymph nodes. Second the para-aortic compartment, containing the thoracic duct, azygos vein and lymph nodes.

As the esophagus traverses the diaphragm through the esophageal hiatus it is loosely attached to it by the phrenico-esophageal liga-ment, also named phrenico-esophageal mem-brane. This ligament wraps the gastro-esophageal junction like a collar and is derived from the endothoracic and transversalis fascias which run above and below the diaphragm respectively (Fig. 2.3). The space between the ligament and the esophagus is called the para-esophageal space and contains loose connective tissue and some fat. By acting as a gliding plane this tissue enables some movement through the hiatus during respi-ration and swallowing. Because the ligament, as extensions of the endothoracic and transversalis fascias, also attaches to the esophagus above and below the diaphragm it simultaneously limits upward and downward movements and therefore stabilizes the esophageal passage through the diaphragm. The upper part of the ligament is the longest and firmest and therefore the ligament is

Fig. 2.3 (**a**) Schematic drawing of the gastroesophageal junction demonstrating two ways in which the endothoracic and transversalis fascias may contribute to the phrenico-esophageal ligament. On the right side the endothoracic fascia fuses with the upper leaflet of the transversalis fascia while on the left side they attach separately to the esophagus. (**b**). Mean distances in centimeters between an imaginary horizontal line through the diaphragm and attachment points of the fascial layers of the phrenico-esophageal ligament. It is demonstrated that the upper part of the ligament is the longest part (From [6])
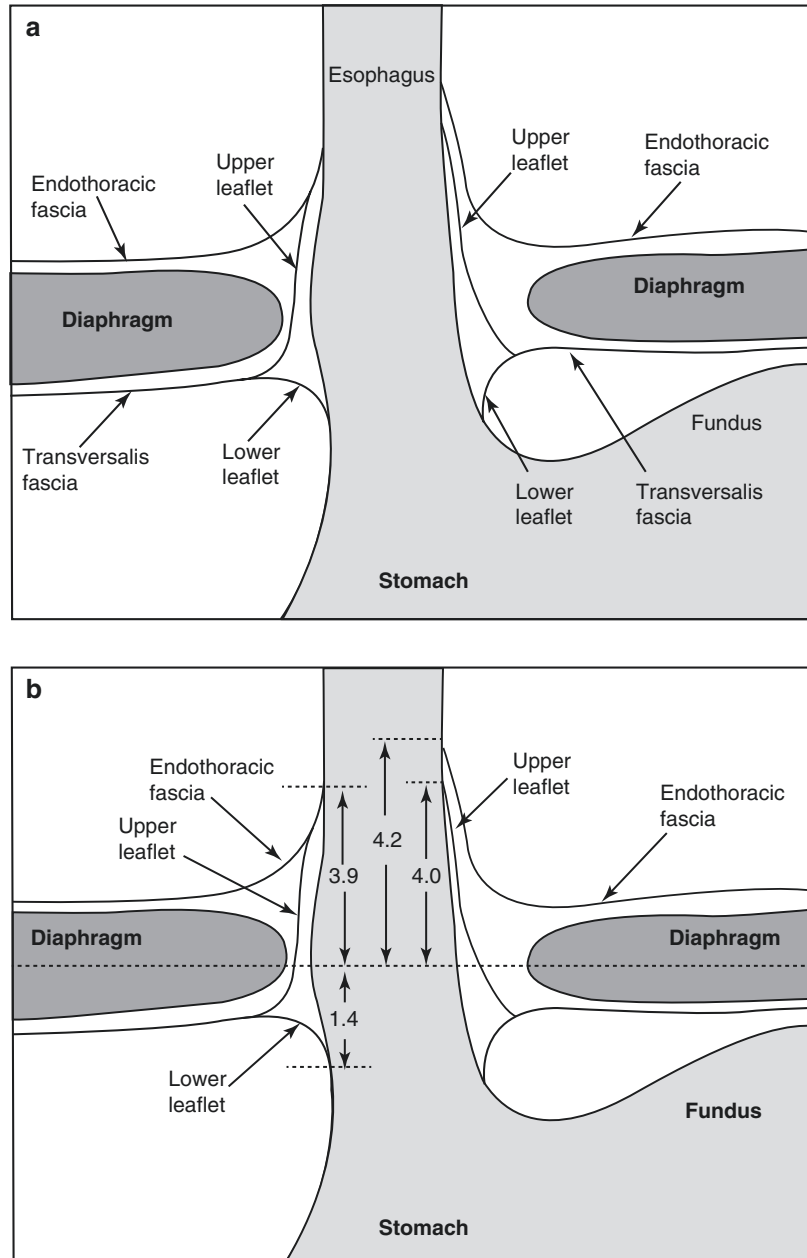
especially important in limiting upward movement of the esophagus during increased intra-abdominal pressure [6]. The phrenico-esophageal ligament contains collagen and elastic fibers. The fiber contents decreases with age and therefore the ligament weakens in the elderly.

2.5 Topographical Relationships

In its course the esophagus has four constrictions. Two of these are caused by the sphincters and are found at its beginning at the pharyngo-esophageal junction and where it traverses the

diaphragm. The other constrictions are where the esophagus is crossed by the aortic arch and where it is crossed by left principal bronchus and they are close to each other. In rest the constrictions are not clear but they become obvious during swallowing when the lumen distends. They are of clinical importance in case of swallowing corpora aliena. Radiographs taken during swallowing clearly demonstrate these constrictions. In a lateral radiograph a slight impression in the anterior aspect of the esophagus becomes visible. It is caused by the left atrium which lies directly anterior to the esophagus with the pericardium in between.

In a previous section the main topographical relationships were mentioned. This section describes additional relationships especially those which are important during esophageal surgery. To the right is the mediastinal pleura and the intervening azygos vein which crosses forwards over the right principal bronchus to enter the superior vena cava. Lower in the posterior mediastinum the thoracic duct runs between the esophagus and the azygos vein. At about the level of the fifth thoracic vertebra it crosses to the left behind the esophagus and then ascends on the left. Further posteriorly on the right side the greater splanchnic nerve can be found on its way to the diaphragm. Between the esophagus in front and the azygos vein and spine behind there is a long pleural recess of the right pleural cavity (Fig. 2.2). Below the pulmonary root the right vagus nerve descends along the esophagus and forms an esophageal plexus with its fellow from the other side. The vagus nerves including the recurrent laryngeal nerves are discussed in more detail in the section on innervation.

A left lateral view demonstrates the aortopulmonary window. This is a space between the arch of the aorta and the pulmonary trunk. Its boundaries in front and behind are the ascending and descending aorta respectively, left is the mediastinal pleura and on the right the left principal bronchus. The aortopulmonary window contains the ligamentum arteriosum, lymph nodes and fat.

The left recurrent laryngeal nerve passes through it, after branching from the left vagus nerve, and then ascends to the neck.

2.6   Vascular Supply

The esophagus is supplied by many arteries. Since the organ is not involved in absorption of food components all supplying arteries are relatively small. Some of the arteries are shared arteries, they share a blood supply with other structures. The shared arteries are: inferior thyroid arteries, bronchial arteries, left gastric artery and quite often (55%) the left inferior phrenic artery. There are four or five proper arteries as well, these arise from the front of the descending aorta between the tracheal bifurcation and the diaphragm and descend obliquely to the esophagus in the aortopulmonary ligament which was described in a previous section. Inside the wall of the esophagus the proper and shared arteries are connected to each other.

The bronchial arteries deserve special mention. They are relatively large and of great importance for the supply of pulmonary tissues. Normally there are three of them, one on the right side arising from the third posterior intercostal artery and two on the left side which arise directly from the aorta. This 'normal' configuration is found in only 40%. Variations are numerous. In 25% two arteries arise from the aorta through a common trunk but are then distributed normally which means that the left lung still receives two arteries. In another common variation (20%) there are only two bronchial arteries, both arising from the aorta [7].

Another variation related to the blood supply of the esophagus is the artery of Belsey. This is an anastomosis between the left gastric and left inferior phrenic arteries and is found at the inferior part of the esophagus.

Blood from the esophagus is collected into a submucosal venous plexus and then into a peri-esophageal venous plexus. From the latter plexus

the thoracic part of the esophagus drains mainly into the azygos vein and to a lesser extent into the hemiazygos and bronchial veins. The cervical part drains into the inferior thyroid and vertebral veins. In the inferior part of the esophagus there are venous connections to the inferior phrenic veins and the left gastric vein, the latter vein connecting to the portal vein. Due to the low intrathoracic pressure the flow in the upper part of the left gastric vein and its esophageal tributaries is normally directed to the thorax.

2.7   Innervation

The vagus nerves are responsible for the innervation of the esophagus. Since these are mixed nerves, containing somatomotor and visceromotor (parasympathetic) nerve fibers, they supply both striated and smooth muscle components of the esophagus as well as the mucous glands in the mucosa. The vagus nerves also carry sensory fibers which come from the esophagus. Esophageal blood vessels have a sympathetic nerve supply originating in the upper 4–6 thoracic spinal cord segments. Visceral afferent pain fibers use sympathetic routes to reach the upper thoracic spinal cord segments. These segments also receive pain fibers from the heart which explains that it is sometimes difficult to determine the origin of the pain.

The upper part of the esophagus is supplied by branches from the recurrent laryngeal nerves. On the right this nerve arises from the vagus nerve at the level of the subclavian artery, curves backwards and ascends behind this artery to the side of the trachea. On the left the nerve arises at the level of the aortic arch, passes through the aortopulmonary window and also ascends to the side of the trachea. While they ascend each recurrent laryngeal nerve gives off 8–14 branches to the trachea and the esophagus [8]. The ascending parts are embedded in connective tissue around the trachea and the esophagus. When these nerves

approach the larynx they are near the groove between the trachea and the esophagus. However, they only tend to lie in this groove just below the entrance into the larynx. Lower, for example 4 cm below the entrance into the larynx, there is a wide variability in position. They may be next to the trachea, next to the esophagus or close to the groove [9]. In its course to the larynx the nerve is crossed by the inferior thyroid artery which may pass anterior or posterior to the nerve, or even may have branches on both sides of the nerve.

At the level of the bifurcation of the trachea and the principal bronchi the vagus nerves form anterior and posterior pulmonary plexuses [10]. Through these nerves many lung functions are controlled, such as the cough reflex, mucus production and bronchus diameter [11]. The right anterior pulmonary plexus is located just above the right pulmonary artery. It is supplied by a median of three vagus nerve branches that arise from the right vagus nerve on its course next to the trachea, containing a small proportion (23%) of the right lung supply. The right posterior pulmonary plexus is located dorsal to the right main bronchus and consists of a median of 13 branches which sequentially arise from the right vagus nerve starting at the level of the superior edge of the main right bronchus (Fig. 2.4). This plexus contains most of the right lung supply (77%). The left anterior pulmonary plexus is located anterosuperior to the left pulmonary artery and is formed by a median of three vagus nerve branches which arise from the vagus nerve as it crosses the aortic arch. As on the right side this plexus has the smallest contribution to the total left lung supply (26%). The large left posterior pulmonary plexus is located dorsal to the left pulmonary artery and left main bronchus, containing 74% of the left lung supply. It consists of a median of 12 branches which sequentially arise from the vagus nerve starting at the superior edge of the left pulmonary artery (Fig. 2.4). Both   posterior   pulmonary   plexuses   are
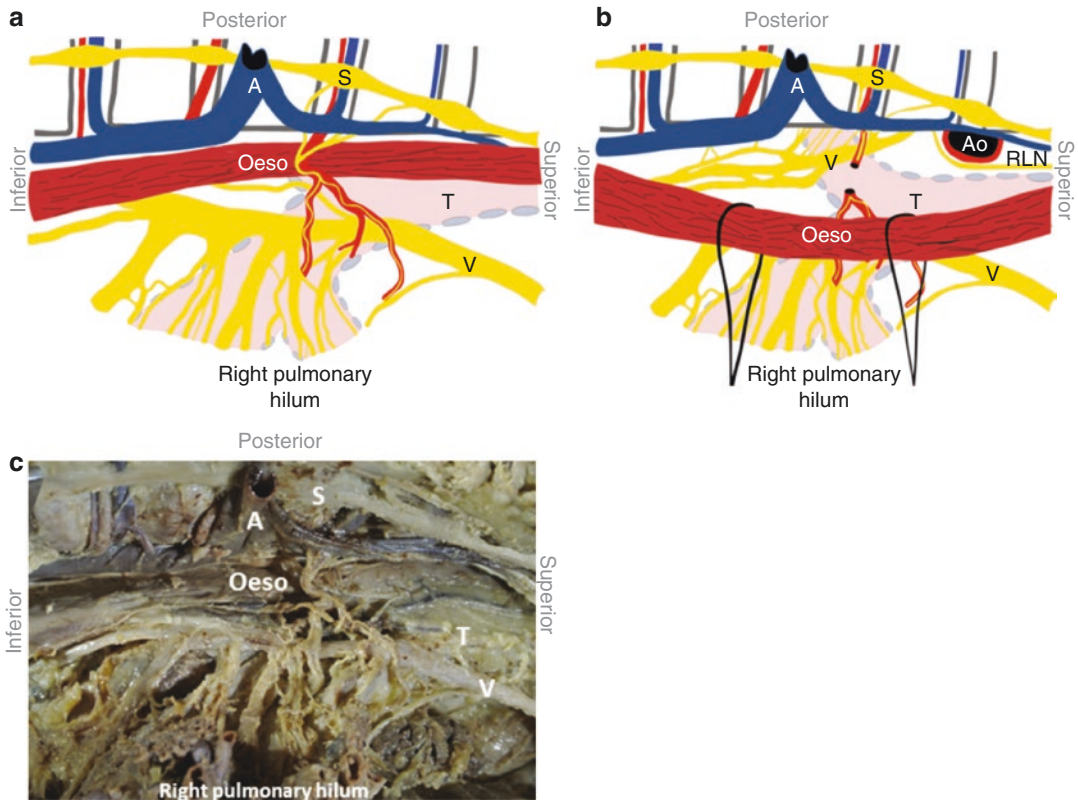
Fig. 2.4 Schematic drawings of the right posterior (**a**) and left posterior (**b**) pulmonary vagus nerve plexuses as encountered during transthoracic esophagectomy from a right lateral approach, including a corresponding photo-graph (**c**). Abbreviations: *A* azygos vein, *Ao* aorta, *Oeso* oesophagus, *RLN* left recurrent laryngeal nerve, *S* sympathetic trunk, *T* trachea, *V* vagus nerve (From [10])

organized segmentally, the most superior branches innervate the superior and middle lung lobes, and the most inferior innervate the inferior lung lobes.

Caudal to the principal bronchi the vagus nerves form a plexus around the lower part of the esophagus. From here the abdomen is reached as anterior and posterior vagal trunks through the esophageal hiatus of the diaphragm.

2.8   Lymphatic Drainage

The esophageal submucosa contains a network of predominantly longitudinally orientated lymph channels. In general the flow in these vessels is diverted from the tracheal bifurca-tion. Lymph is collected by deep cervical, mediastinal and left gastric (and from there to coeliac) lymph nodes. The variation in the number of lymph nodes is large, for example the number of mediastinal lymph nodes ranges from 11 up to 54 lymph nodes [12]. The medi-astinal lymph nodes are generally grouped using the lymph node map develop by the International Association for the Study of Lung Cancer (Fig. 2.5) [13, 14]. Abdominal lymph nodes are classified using the lymph node map developed by the Japanese society for gastric cancer (Fig. 2.6) [15]. Due to the network of longitudinally orientated lymph channels lymph node metastasis can occur far from the primary tumor and the sentinel node concept does not apply to esophageal cancer [16].

Fig. 2.5 Important mediastinal lymph node stations as seen during thoracolaparoscopic esophagectomy in prone position. Abbreviations: *LN* lymph node, *R* right, *L* left (From [13])
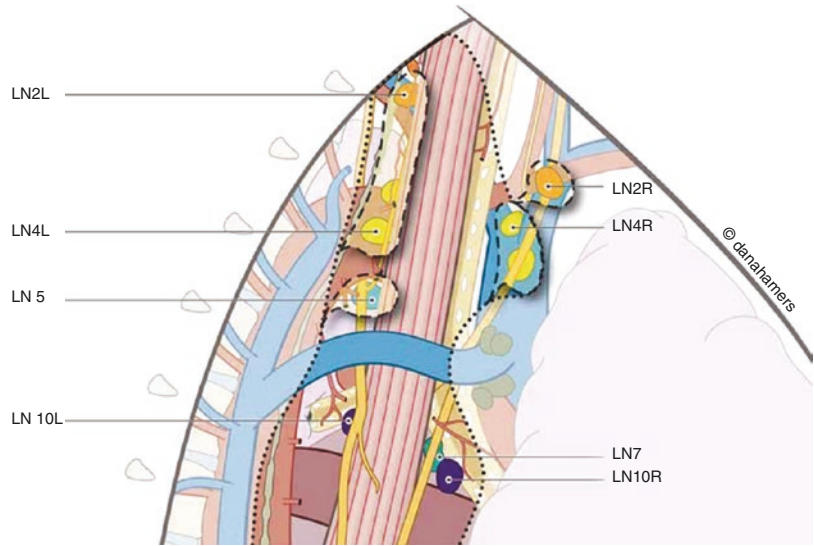
Fig. 2.6 Gastric lymph node map as developed by the Japanese society for gastric cancer. Abbreviations: *APIS* a. phrenica inferior sinistra, *AGES* a. gastroepiploica sinistra, *AGB* aa. gastricae breves, *VGED* v. gastroepiploica dextra, *VCDA* v. colica dextra accessoria, *AGSA* a. gastrica sinistra accessoria, *REGAP* ramus esophagogastricus ascendens posterior, *VCM* v. colica media, *VCD* v. colica dextra, *VPDIA* v. pancreaticoduodenalis inferior anterior; *TGC* truncus gastrocolicus, *VMS* v. mesenterica superior, *VL* v. lienalis, *AHC* a. hepatica communis (From [15])
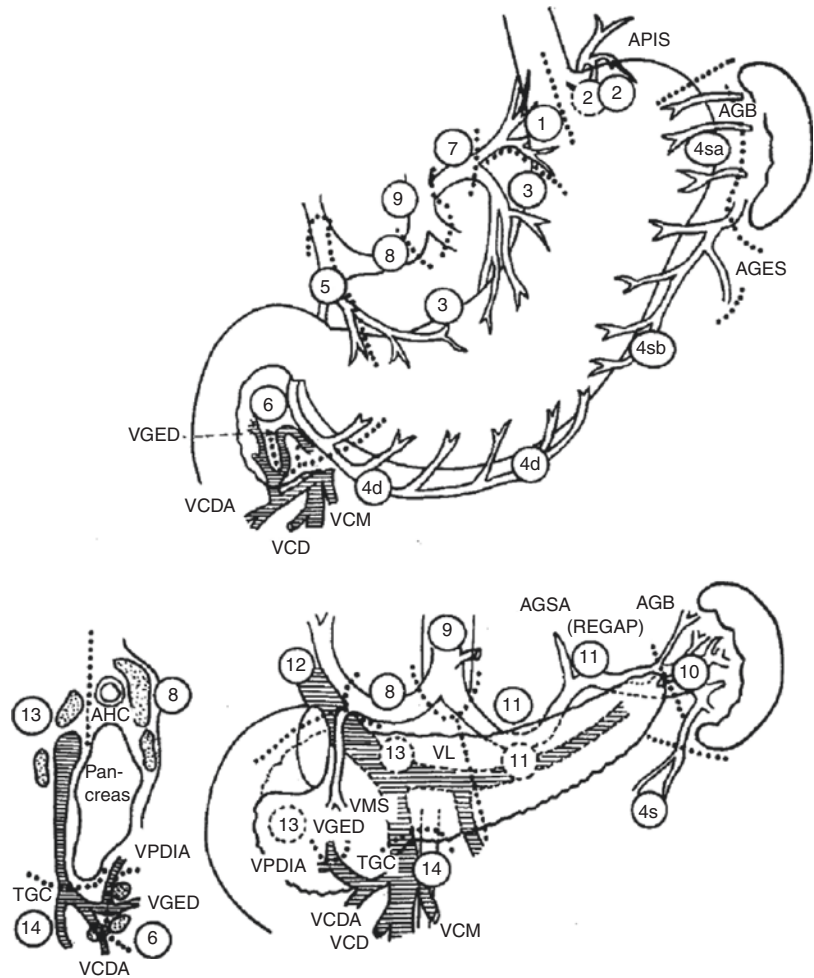
2.9   Concluding Remarks

The function and course of the esophagus set requirements for its construction and attachments. Several sphincters, namely the UES, the LES and the right crus of the diaphragm, keep both ends of the esophagus closed, except during swallowing. The esophagus is embedded in loose connective tissue which allows much freedom of movement. It is attached to the environment by fibro-elastic structures, such as the phrenico-esophageal ligament and by the recently discovered aorto-esophageal ligament. Among the most important topographical relationships are the aortopulmonary window, the azygos vein, the thoracic duct and the recurrent laryngeal nerves. The arterial blood supply is diffuse and consists of shared and proper arteries. Likewise, several vessels are involved in the venous drainage and there is a diffuse lymphatic drainage. The nerve supply is by the vagus nerves which, after contributing to the pulmonary plexuses, form an esophageal plexus from where two vagal trunks reach the abdomen.

References

1. Grodinsky M, Holyoke EA. The fascia and fascial spaces of the head, neck and adjacent regions. Am J Anat. 1938;63:367–408.
2. Guidera AK, Dawes PJ, Fong A, Stringer MD. Head and neck fascia and compartments: no space for spaces. Head Neck. 2014;36:1058–68.
3. Miller L, Vegesna A, Ruggieri M, Braverman A. Normal and abnormal physiology, pharmacology, and anatomy of the gastroesophageal junction high-pressure zone. Ann N Y Acad Sci. 2016; 1380(1):48–57.
4. Cuesta MA, Weijs TJ, Bleys RL, van Hillegersberg R, van Berge Henegouwen MI, Gisbertz SS, Ruurda JP, Straatman J, Osugi H, van der Peet DL. A new concept of the anatomy of the thoracic oesophagus: the meso-oesophagus. Observational study during thoracoscopic esophagectomy. Surg Endosc. 2015; 29:2576–82.
5. Weijs TJ, Goense L, van Rossum PS, Meijer GJ, van Lier AL, Wessels FJ, Braat MN, Lips IM, Ruurda JP, Cuesta MA, van Hillegersberg R, Bleys RL. The peri-esophageal connective tissue layers and related compartments: visualization by histology and magnetic resonance imaging. J Anat. 2017;230(2):262–71.
6. Apaydin N, Uz A, Evirgen O, Loukas M, Tubbs RS, Elhan A. The phrenico-esophageal ligament: an anatomical study. Surg Radiol Anat. 2008;30:29–36.
7. Cauldwell EW, Siekert RG, Lininger RE, Anson BJ. The bronchial arteries; an anatomic study of 150 human cadavers. Surg Gynecol Obstet. 1948;86:395–412.
8. Yalcin B, Tunali S, Ozan H. Extralaryngeal division of the recurrent laryngeal nerve: a new description for the inferior laryngeal nerve. Surg Radiol Anat. 2008;30:215–20.
9. Liebermann-Meffert DM, Walbrun B, Hiebert CA, Siewert JR. Recurrent and superior laryngeal nerves: a new look with implications for the esophageal surgeon. Ann Thorac Surg. 1999;67:217–23.
10. Weijs TJ, Ruurda JP, Luyer MD, Nieuwenhuijzen GA, van Hillegersberg R, Bleys RL. Topography and extent of pulmonary vagus nerve supply with respect to transthoracic oesophagectomy. J Anat. 2015;227:431–9.
11. Mazzone SB, Canning BJ. Autonomic neural control of the airways. Handb Clin Neurol. 2013;117:215–28.
12. Ziyade S, Pinarbasili NB, Ziyade N, Akdemir OC, Sahin F, Soysal Ö, Toker A. Determination of standard number, size and weight of mediastinal lymph nodes in postmortem examinations: reflection on lung cancer surgery. J Cardiothorac Surg. 2013;8:94.
13. Cuesta MA, van der Wielen N, Weijs TJ, Bleys RL, Gisbertz SS, van Duijvendijk P, van Hillegersberg R, Ruurda JP, van Berge Henegouwen MI, Straatman J, Osugi H, van der Peet DL. Surgical anatomy of the supracarinal esophagus based on a minimally invasive approach: vascular and nervous anatomy and technical steps to resection and lymphadenectomy. Surg Endosc. 2017;31:1863–70.
14. Rusch VW, Asamura H, Watanabe H, Giroux DJ, Rami-Porta R, Goldstraw P, Members of IASLC Staging Committee. The IASLC lung cancer staging project: a proposal for a new international lymph node map in the forthcoming seventh edition of the TNM classification for lung cancer. J Thorac Oncol. 2009;4:568–77.
15. Kajitani T. The general rules for the gastric cancer study in surgery and pathology. Part I Clinical classification. Jpn J Surg. 1981;11:127–39.
16. Boone J, Hobbelink MG, Schipper ME, Vleggaar FP, Borel Rinkes IH, de Haas RJ, Ruurda JP, van Hillegersberg R. Sentinel node biopsy during thoraco-laparoscopic esophagectomy for advanced esophageal cancer. World J Surg Oncol. 2016;14:117.