Chapter 4
Radiographic Anatomy

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Imaging of the esophagus is best approached in a multidisciplinary fashion. The surgeon and radiologist bring different attributes to the interpretation of the images, and a dialogue between all members of the team caring for the patient is essential. Preoperative discussion of a patient's images can allow appropriate staging of any tumor and allow selection of the most appropriate neoadjuvant therapy and operative approach. Further discussion regarding postoperative anatomy is essential for accurate interpretation of the images; it is especially important for those patients in whom a complication such as an anastomotic leak or obstruction is encountered. This chapter focuses on imaging the esophagus using a variety of techniques to image benign and malignant pathology. The upper gastrointestinal (GI) contrast swallow examination, plain x-ray, CT imaging, MR imaging, and positron emission tomography (PET) imaging are reviewed (Figs. 4.1–4.21). Ultrasound imaging of the esophagus is reviewed in Chap. 5.

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Upper Gastrointestinal Contrast Swallow Examination

Barium swallow, esophagram, or upper GI study involves the patient swallowing a contrast agent to identify structural and functional abnormalities of the esophagus. In the postoperative setting, if a leak is suspected, the test will start with a water-soluble agent like iohexol (Omnipaque™) or diatrizoic acid (Gastrografin®); if no leak is detected, barium may be used. The ordering practitioner should be aware of the densities of materials used for upper GI studies. Barium will preclude good imaging if a CT scan of the chest to view the esophagus is required later or if a leak is present, as extravasation of the barium remains within the leak. Adequate CT images cannot be obtained until enough time has passed for the contrast to leave the esophagus or the cavity formed by the leak, so it is common to image first with a CT scan and later with a swallow if a leak is suspected. Gastrografin pneumonitis and pneumonia can be fatal, and many institutions have changed to using vascular contrast agents like Omnipaque or iodixanol (Visipaque™). Omnipaque dissolves quickly after extravasation, is less caustic if aspirated, and is less expensive than Visipaque, which was originally developed for patients with renal failure. Barium remains the gold standard for imaging subtle mucosal changes and anatomic abnormalities of the esophagus. The individual images that are recorded during these swallow examinations are only a representative selection of the study obtained, however. It is best for the surgeon to attend the examination and watch the real-time pictures of the study, to correlate his or her understanding of the postoperative anatomy with the images obtained.

Thick barium (high density and high viscosity) and thin barium (lower density, low viscosity) may be used for examinations. Thick barium is useful when evaluating for aspiration during a modified barium swallow evaluation performed by a radiologist and speech pathologist. Other densities of food (e.g., applesauce, marshmallows, or pudding) may also be mixed with barium to assess swallowing with different textures. In the outpatient setting, barium swallows may be used to assess strictures (benign or malignant) in patients with dysphagia. A barium tablet also may be swallowed to see if there is any delay in passage through the esophagus, indicating a stricture.

CT Scans

CT images of the esophagus are usually obtained in order to assess esophageal perforation and local contamination and for the staging of esophageal tumors. For tumor staging, CT will not reliably determine T stage, but it sometimes can help to determine whether there is a fat plane between the esophageal lesion and local structures. If there is doubt with regard to invasion of local structures, endoscopic ultrasound (EUS), intravascular ultrasound (IVUS), and MRI may help to differentiate which lesions are growing into the aorta, lung, mediastinal structures, or

other great vessels. CT images are also important for determining evidence of metastatic spread. If esophageal perforation has occurred, pneumomediastinum, free fluid or fluid collections, and a left pleural effusion may commonly be seen on CT scans.

When evaluating the esophagus using CT scanning, if no lumen can be seen, half of the maximum thickness of the esophagus is a surrogate for the diameter of the esophagus. More recently, three-dimensional CT models can be printed from two-dimensional CT images, and with the administration of an oral effervescent agent, the esophagus can be distended and relationships to other mediastinal structures can be accurately delineated. A positive enteric contrast agent is given to the patient prior to administration of effervescent granules. Positive contrast agents used in our practice include an iso-osmotic iodinated agent diluted with water for postoperative patients (Omnipaque 300; GE Healthcare, Cork, Ireland; 15 mL added to a 500-mL bottle of water) or barium sulfate suspension for preoperative patients (Berry Smoothie Readi-Cat two barium sulfate suspension 2.1 % w/v; E-Z-EM Inc., Lake Success, NY). The patient is then given a packet of effervescent granules containing sodium bicarbonate (E-Z-GAS II; E-Z-EM Inc., Lake Success, NY) to release carbon dioxide within the esophagus. The effervescent granules are mixed with approximately 20 mL of water and swallowed, or injected via a tube if the patient cannot swallow. After the patient is placed in the decubitus position on the scanner table, several more swallows or injections of positive enteric contrast agent are given to fill a redundant or patulous esophagus. Images are generally acquired in two positions using automatic exposure control (AEC) to ensure similar image noise across the acquired volume. Standard low-dose techniques such as kV selection, AEC, and iterative reconstruction are used to create high contrast differences between the esophageal wall, air, periesophageal fat, and positive enteric contrast. Routine multiplanar images used for diagnostic purposes are obtained. From these data, additional thin (1-mm) images are reconstructed in order to minimize stair-step artifacts in 3D printing. The imaging data, stored in Digital Imaging and Communication in Medicine (DICOM) format, is imported into proprietary software (Materialise, Belgium). The imaging data are then segmented using Hounsfield units (as well as hand segmented) to provide greater accuracy of the critical structures involved. (Hounsfield units are an indicator of radiodensity on CT scanning [air, -1000; water, 0; blood, 30–40; soft tissue, 100–300] and may help to determine if duplication cysts near the esophagus are hemorrhagic or are filled with thin fluid.) The segmented data are converted into a virtual 3D anatomic model, which is then exported into an STL (STereoLithography) file format. The final STL file is reimported into the source imaging data to ensure that its outline accurately matches what was initially segmented. The STL files are imported into Mimics software (Materialise, Belgium) for printing (Objet350 Connex multi-material 3D printer; Stratasys, Rehovot, Israel). Using the 3D printing software, different colors are assigned to the various anatomic structures, and several materials, both rigid and flexible, are selected. Life-size models are then printed using liquid photopolymers on the polyjet 3D printer. The material is printed with surrounding support material, which is washed off after the model is created. These life-size anatomic models can

be used for multidisciplinary preoperative discussions, surgical planning, and as part of the patient education and consent process.

PET Imaging

PET imaging in patients with esophageal disease is used primarily for staging esophageal cancer. PET scanning utilizes fluorodeoxyglucose (FDG) to determine the metabolic activity, expressed in standardized uptake value (SUV) of tissues. It is important to note that disease smaller than 8 mm typically is not detected by PET scanning. Additionally, other pathology such as reflux can cause mild PET activity in the lower esophagus, and mucin-producing tumors typically are not FDG-avid. EUS is better for staging local disease. Invasion into the thoracic aorta is not imaged well with PET, which can show false positives. Diffusion-weighted MRI may be superior to PET when evaluating patients after neoadjuvant therapy. PET is good at detecting synchronous primary lesions, however—especially unsuspected metastasis outside the esophagus.

Fig. 4.1 Normal esophageal images seen on plain film. In this normal chest x-ray, the esophagus has been highlighted for better identification. The esophagus extends from C6 to T10 and is approximately 25–30 cm long. Cephalad, the esophagus is posterior to the trachea and subsequently is posterior to the left atrium. The esophagus deviates to the left of the midline caudad to the left mainstem bronchus. UES—upper esophageal sphincter
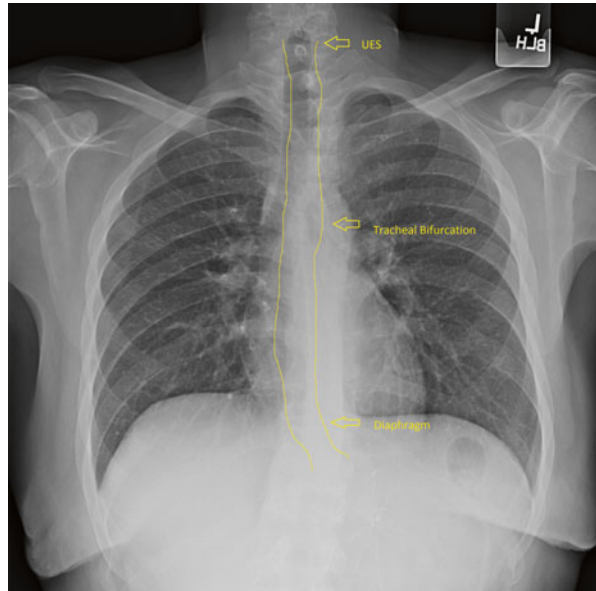
Fig. 4.2 Normal esopha-
gram; the upper esophagus
begins just below the larynx
progressing through the
upper esophagus, enters the
thoracic inlet, passes behind
the trachea, traverses the
diaphragm anterior to the
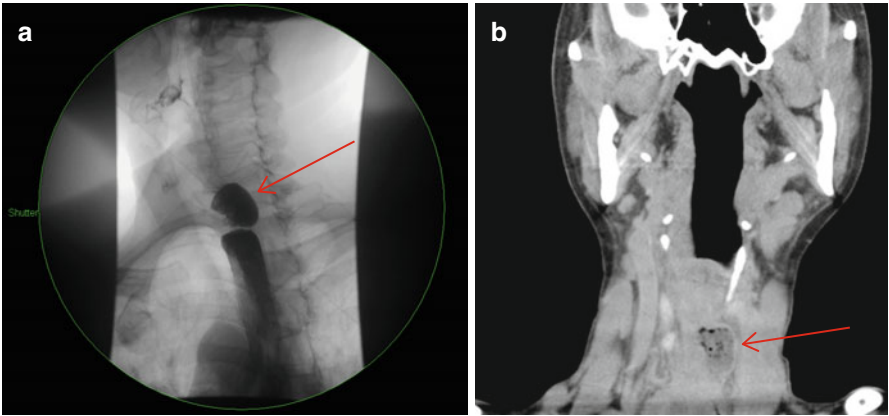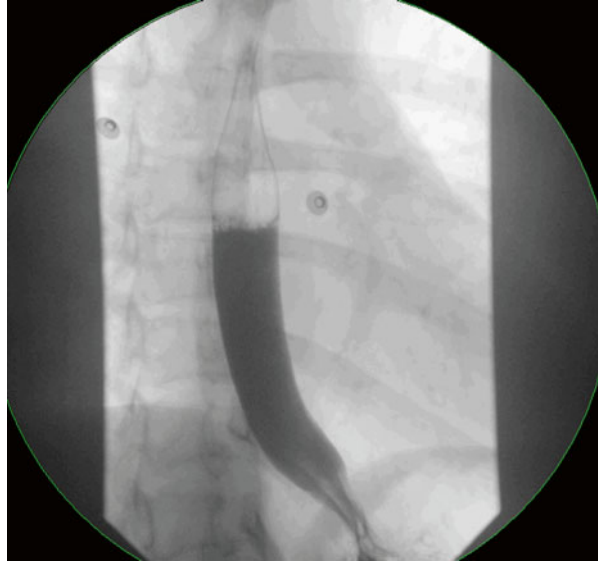aorta, and enters the
stomach in the abdomen

Fig. 4.3 Upper esophageal (Zenker's) diverticulum, often caused by a hypertonic cricopharyn-
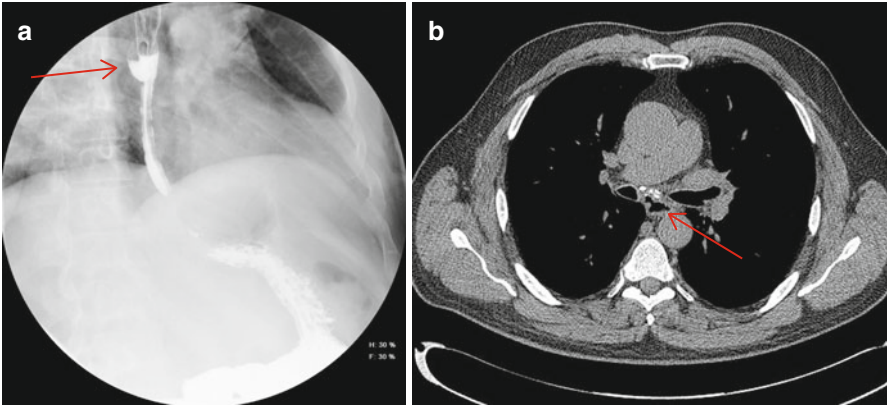geus muscle. (**a**) Contrast esophagram. (**b**) CT scan. *Arrows* denote the diverticulum

Fig. 4.4 Midesophageal diverticulum, often caused by traction from tuberculosis or an inflamed lymph node. (**a**) Contrast esophagram. (**b**) CT scan. *Arrows* denote the traction diverticulum
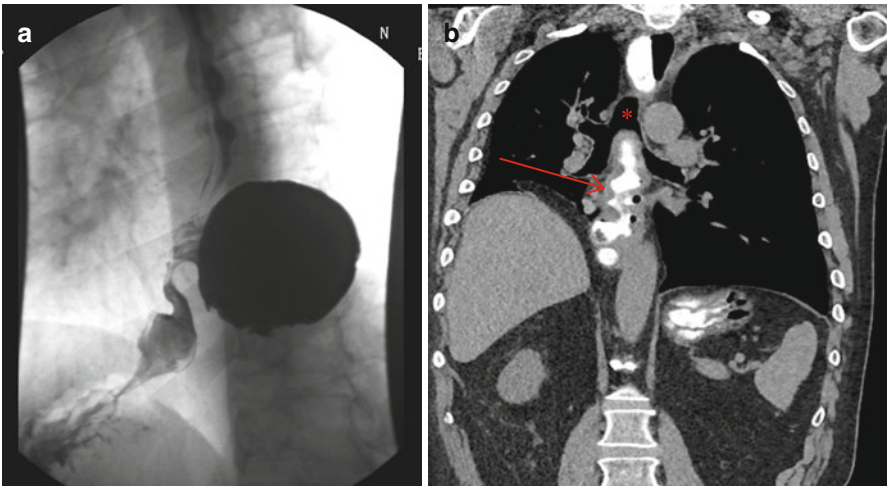
Fig. 4.5 Lower esophageal diverticulum, often caused by pulsion from a wall defect and a hypertonic lower esophageal sphincter. (**a**) Contrast esophagram. (**b**) CT scan of a complex multi-site lower esophageal diverticular disease extending from the carina to the diaphragm. * denotes trachea and *arrow* shows the esophagus with multiple diverticula
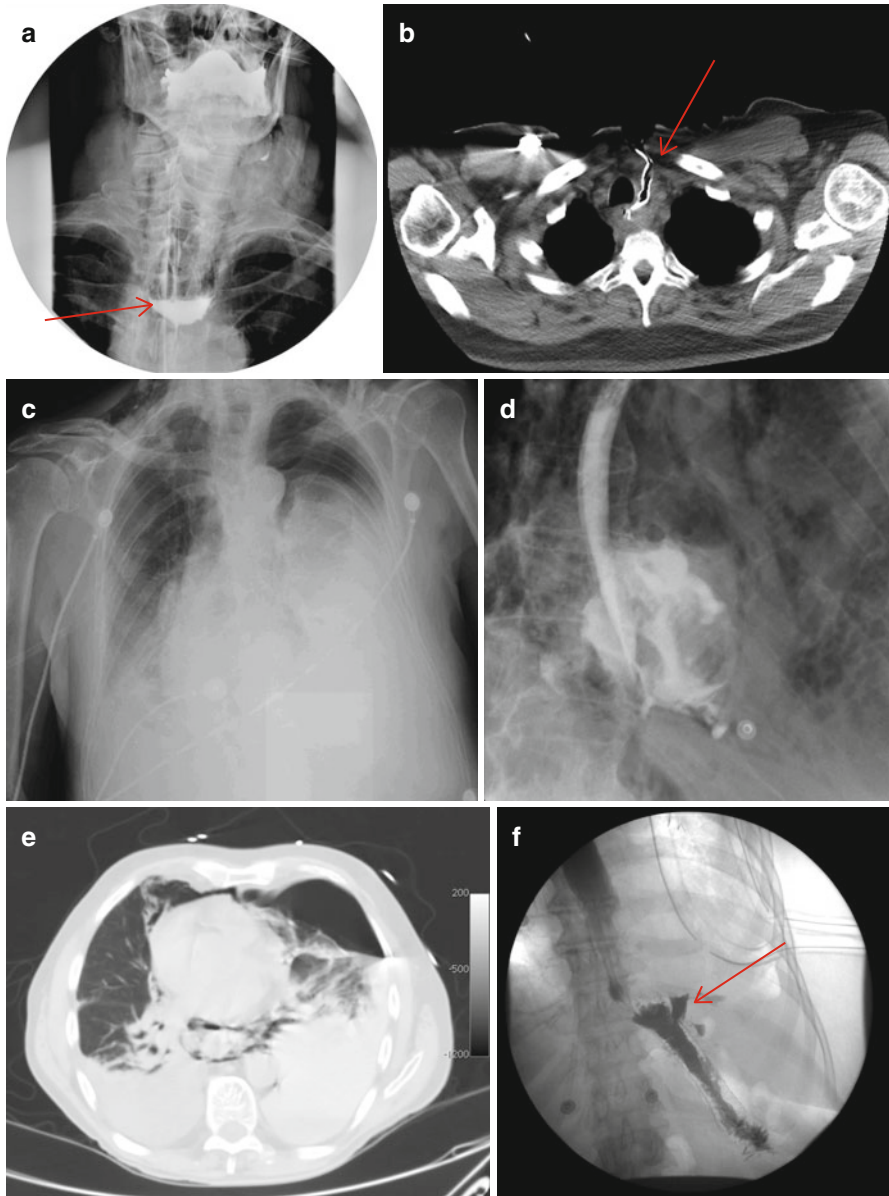
Fig. 4.6 Esophageal leaks: (**a**) Esophageal leak in the neck: contrast esophagram. *Arrow* denotes the pooling of contrast extra-luminally from cervical esophageal perforation; (**b**) Esophageal leak in the neck: CT scan. *Arrow* denotes extra-luminal contrast leaking from the esophagus. (**c**) Esophageal leakage in the chest: chest radiograph; (**d**) Esophageal leak in the chest: contrast esophagram; (**e**) Esophageal leak in the chest: CT scan. (**f**) Esophageal leakage in the abdomen above a deployed esophageal stent, demonstrated on a contrast esophagram. *Arrow* denotes leakage of contrast from proximal aspect of esophageal stent. This is a type I leak. Stephens et al. [1]
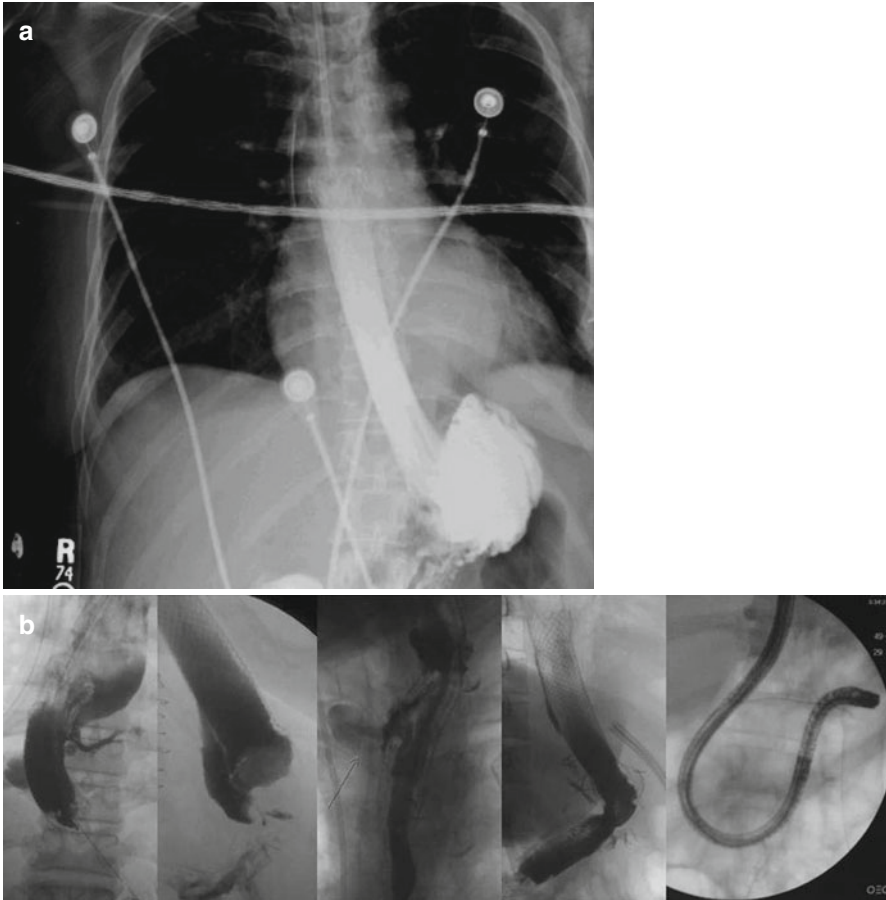
Fig. 4.7 (**a**) Esophageal stent deployed to seal a leak that was located at the gastro-esophageal junction. (**b**) Persistent esophageal leakage after esophageal stenting using a leak classification system (*left to right*): Type I (proximal leak), Type II (distal leak), Type III (leak in the stent lining), Type IV (leak between the stents), Type V (leak from a migrated stent) (Reprinted from Stephens et al. [1]; with permission from Elsevier)
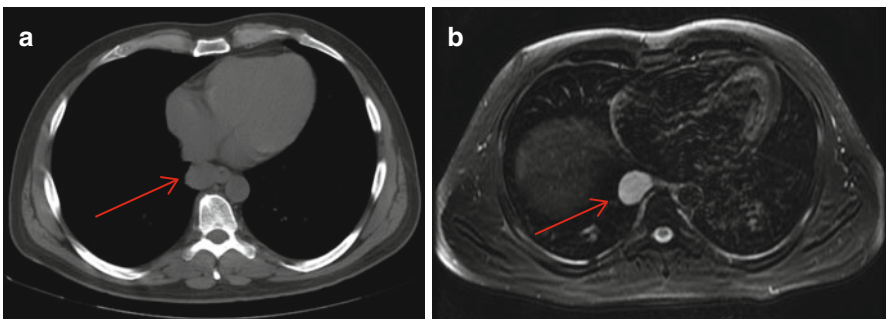
Fig. 4.8 Esophageal duplications cyst. (**a**) CT scan; (**b**) MRI. The *arrows* denote the position of the cyst

Fig. 4.9 Contrast
esophagram demonstrating
a distal esophageal
malignant stricture
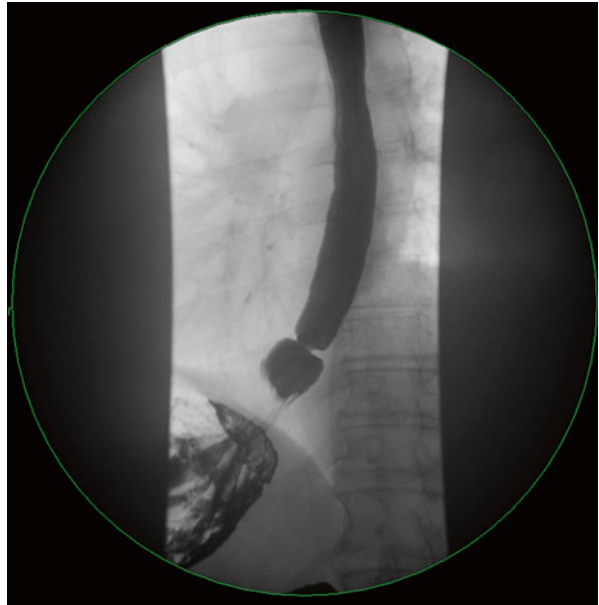
Fig. 4.10 Contrast
esophagram demonstrating
an esophageal web
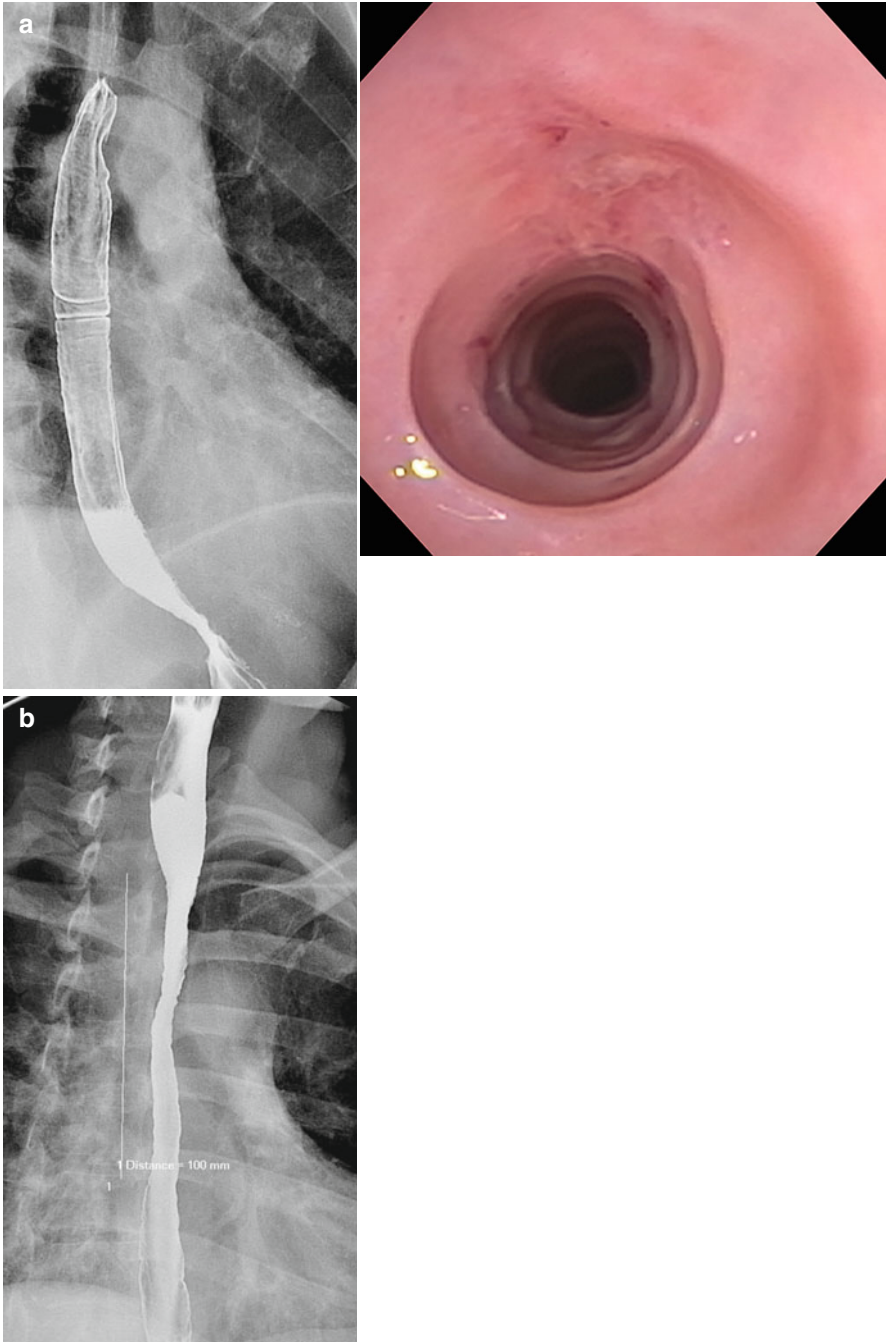
Fig. 4.11 (**a**) Contrast esophagram (*left*) and upper gastrointestinal endoscopy (*right*) demonstrating ringed esophagus seen in a patient with eosinophilic esophagitis. (**b**) Contrast esophagram demonstrating a long stricture in a patient with eosinophilic esophagitis and dysphagia. (**c**) Constrast esophagram from a patient with eosinophilic esophagitis demonstrating esophageal rings (*left*) and appearances following proton pump inhibitor treatment (*right*)
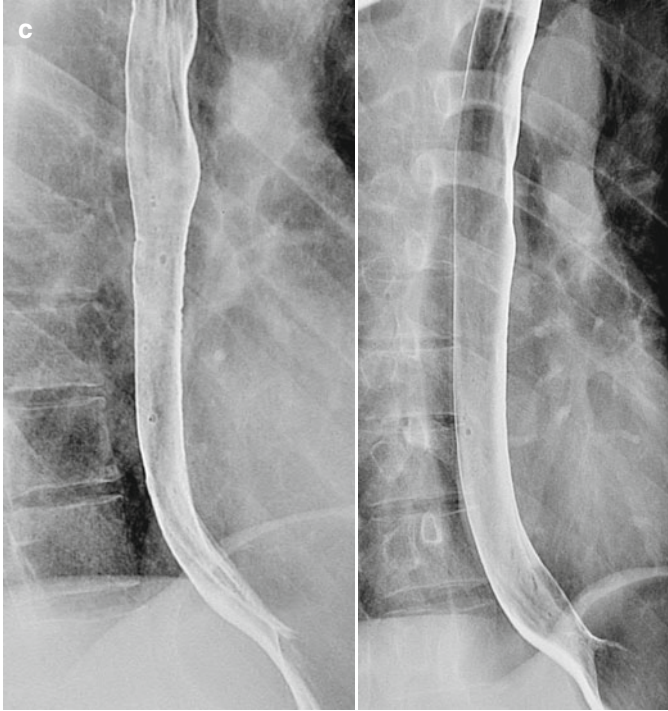
Fig. 4.11 (continued)
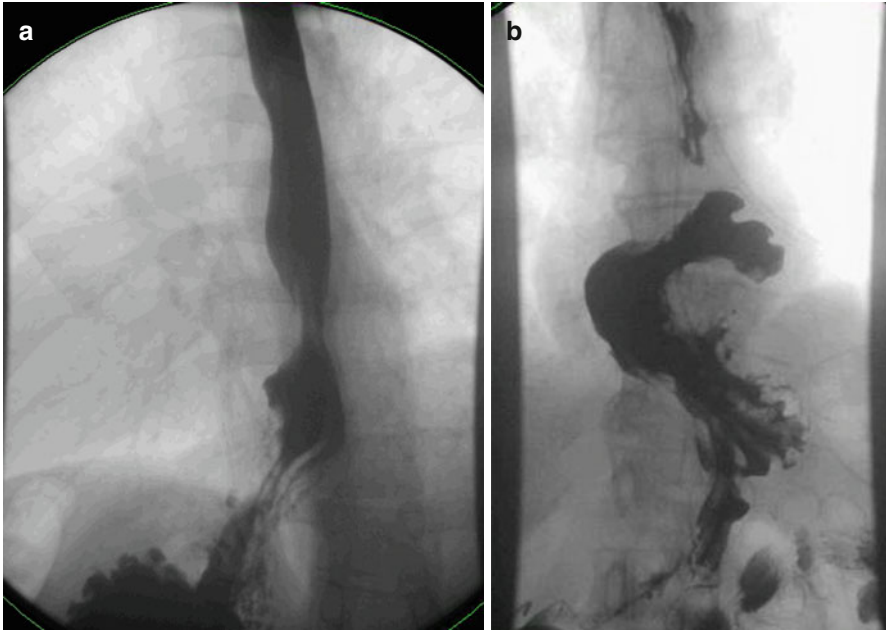
Fig. 4.12 Paraesophageal hernias (type I–IV). (**a**) Type 1. (**b**) Type II. (**c**) Type III: contrast esophagram; (**d**) Type III: CT in axial section demonstrating a type III hernia with organoaxial volvulus; (**e**) CT scan of the same patient with organoaxial volvulus in coronal section. (**f**) Type IV: axial CT scan showing a dilated stomach in a man with a type IV hernia causing gastric outlet obstruction secondary to the hernia containing duodenum; (**g**) Axial CT of the same patient demonstrating intrathoracic duodenum; (**h**) Coronal CT image from the same patient demonstrating the type IV paraesophageal hernia
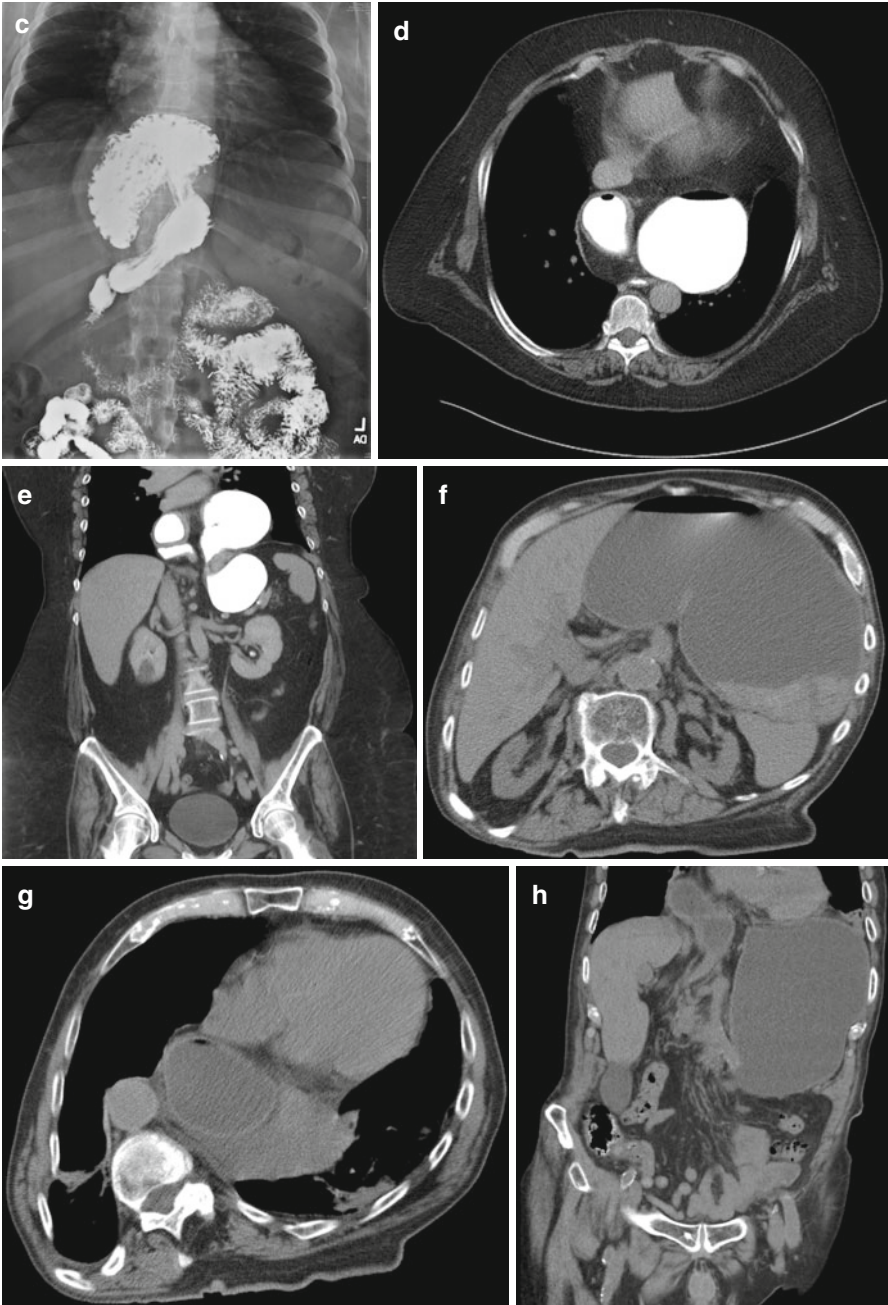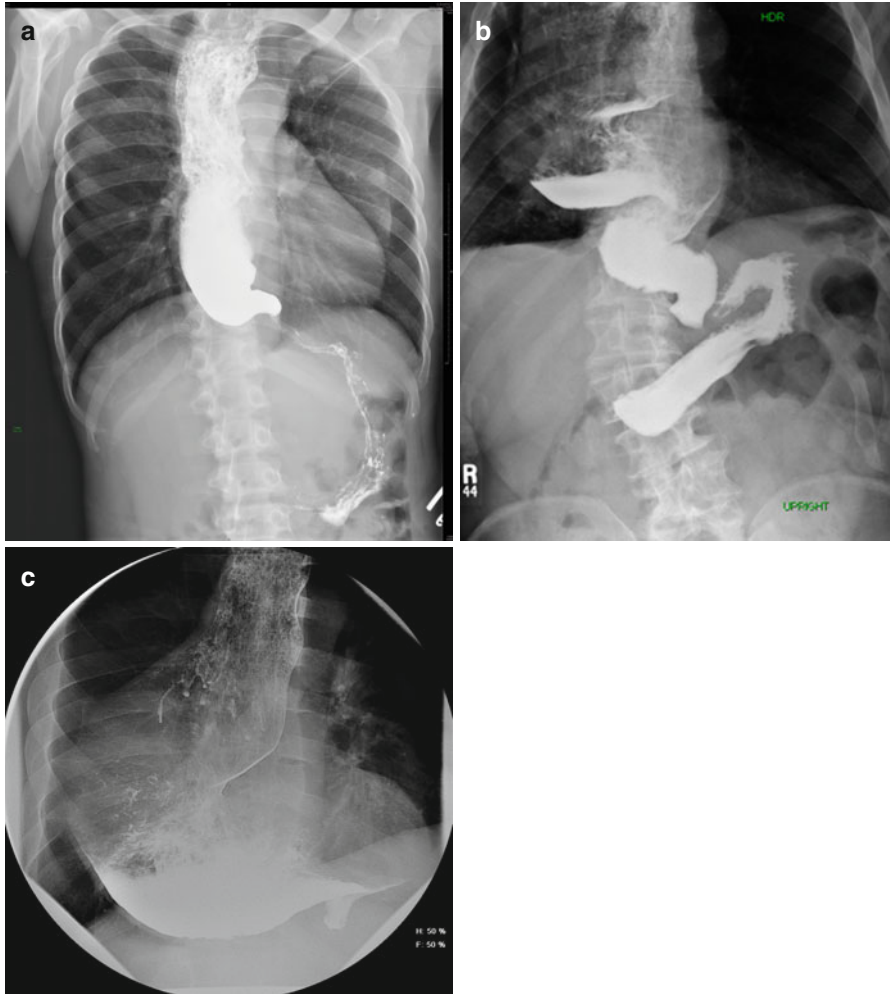
Fig. 4.12 (continued)

Fig. 4.13 Achalasia of the esophagus. (**a**) Contrast esophagram showing achalasia. (**b**) Contrast esophagram with sigmoid achalasia. (**c**) Contrast esophagram of achalasia with megaesophagus
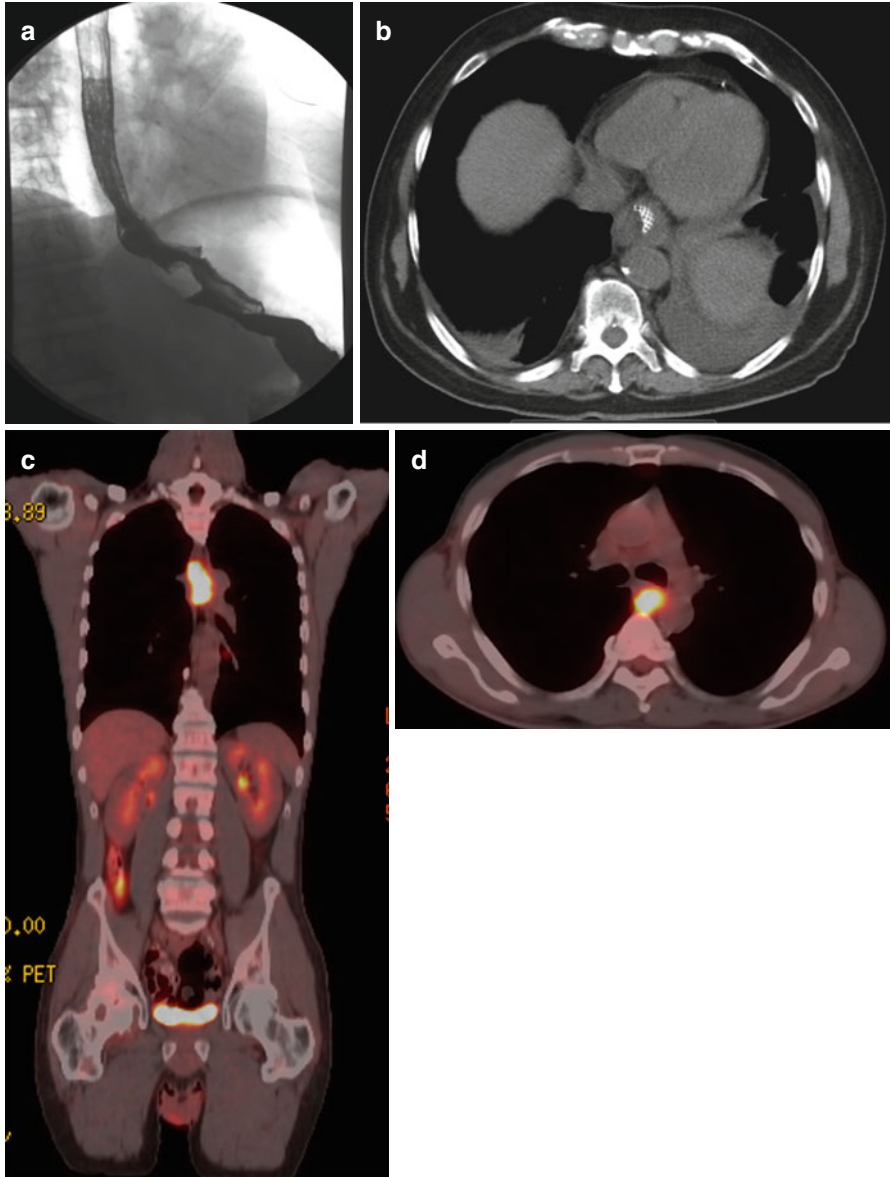
Fig. 4.14 Esophageal cancer. (**a**) Esophagram demonstrating a distal esophageal carcinoma. (**b**) CT scan demonstrating aortic invasion by an esophageal carcinoma that has been stented. PET-CT imaging demonstrating a squamous esophageal cancer: coronal view (**c**); axial view (**d**)
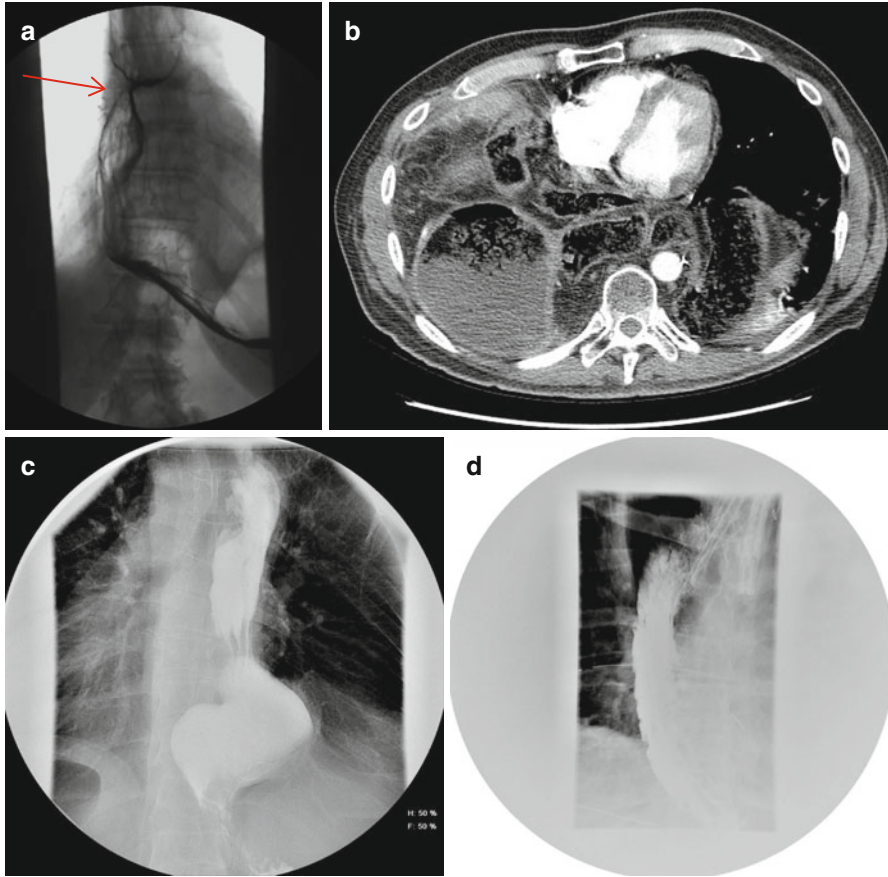
Fig. 4.15 Images seen after esophagectomy. (**a**) Esophagram of anastomotic stricture after Ivor Lewis esophagectomy. *Arrow* denotes the stricture. (**b**) Axial CT scan showing diaphragmatic hernia after Ivor Lewis esophagectomy. (**c**) Postoperative conduit dilatation after Ivor Lewis esophagectomy. (**d**) Esophagectomy with the anastomosis in the chest
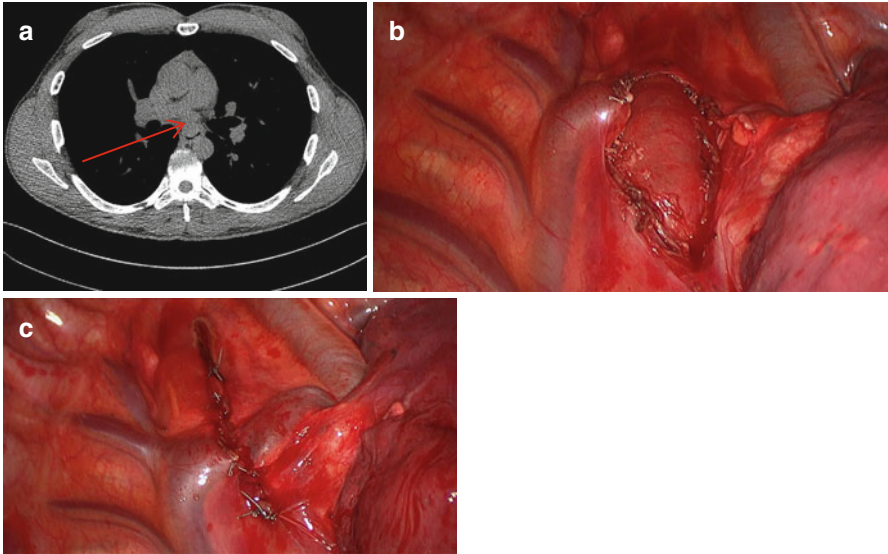
Fig. 4.16 Esophageal leiomyoma: (a) CT images showing esophageal mass, *Arrow* shows the location of the esophageal leiomyoma causing intraluminal narrowing; (b) intraoperative appearances following resection of the leiomyoma; (c) pleural repair over the oesophageal mucosa
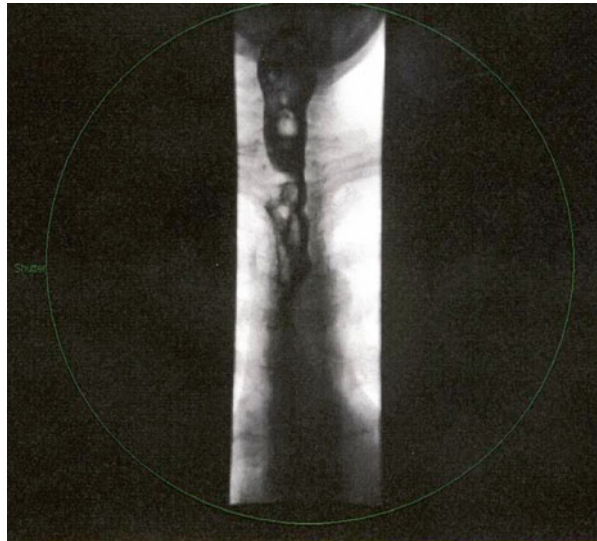

Fig. 4.17 Radiation stricture after mantle radiation for lymphoma

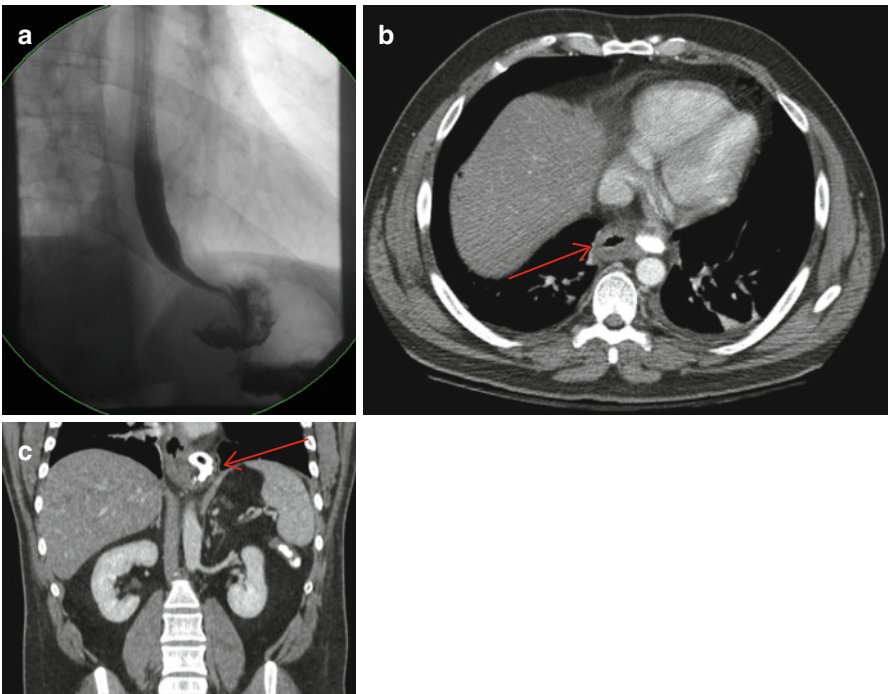**Fig. 4.18** Contrast
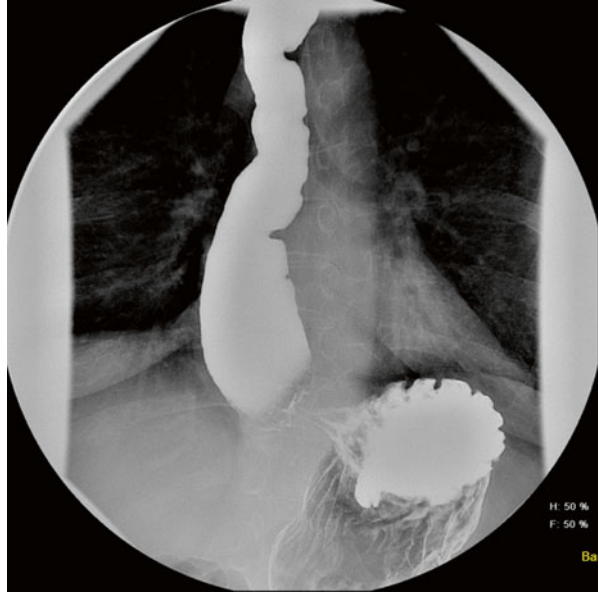swallow demonstrating
scleroderma esophagus

Fig. 4.19 Esophageal images after antireflux surgery. (**a**) Normal appearance of esophagram after
a laparoscopic Nissen fundoplication. (**b**, **c**) CT images of slipped Toupet fundoplication following
prolonged postoperative vomiting: axial section (**b**) showing wrap herniation above the diaphragm;
coronal section (**c**). *Arrows* show the wrap herniation above the diaphragm
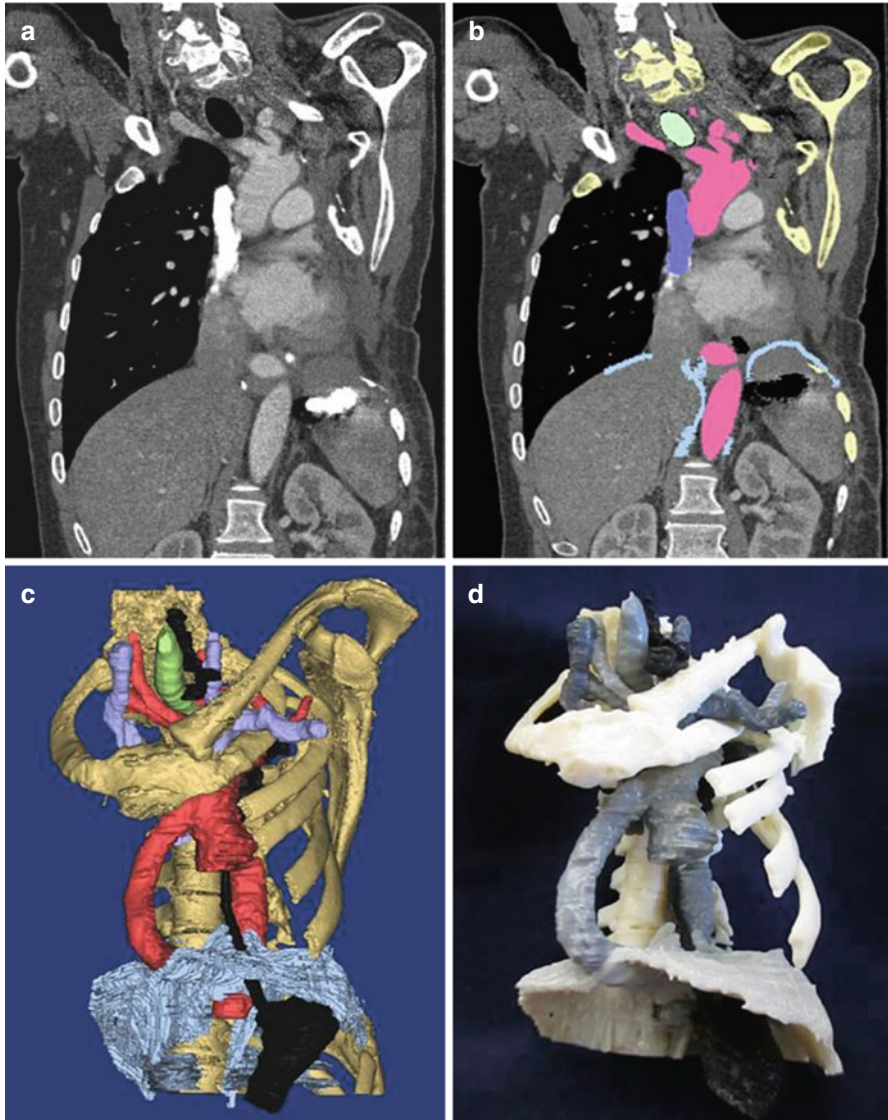
Fig. 4.20 Development of a three-dimensional anatomic model for a patient with an aorto-esophageal fistula, to allow a combined approach of surgical and endoscopic management. (**a**) The coronal CT scan images, (**b**) the segmentation process of selecting which anatomic features will be printed, (**c**) the three-dimensional computerized model that is used to create the .stl file and (**d**) the three-dimensional model after printing (From Dickinson et al. [2]; with permission)
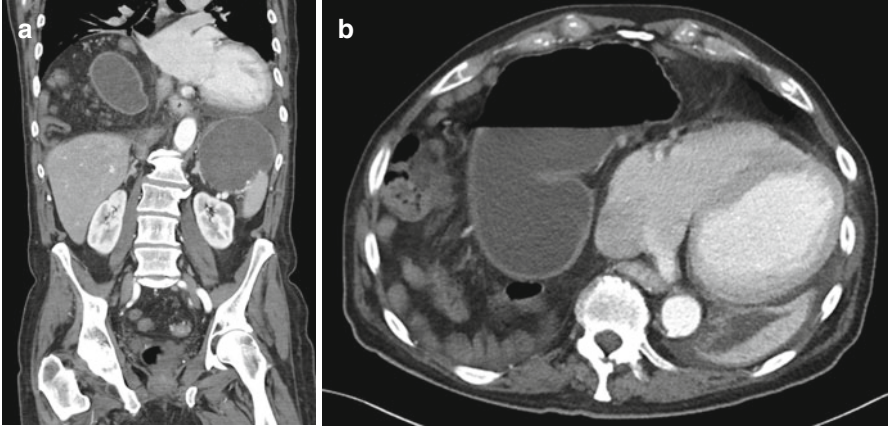
Fig. 4.21 Morgagni hernia: (**a**) sagittal CT scan demonstrating the anterior diaphragmatic defect containing stomach; (**b**) axial CT scan of the same patient, demonstrating gastric distension secondary to this hernia

References

1. Stephens EH, Correa AM, Kim MP, Gaur P, Blackmon SH. Classification of esophageal stent leaks: leak presentation, complications, and management. Ann Thorac Surg. 2014;98(1): 297–303; discussion 303–4.
2. Dickinson KJ, Matsumoto J, Cassivi SD, Reinersman JM, Fletcher JG, Morris J, Wong Kee Song LM, Blackmon SH. Individualizing management of complex esophageal pathology using three-dimensional printed Models. Ann Thorac Surg. 2015;100(2):692–7.

Suggested Reading

Ekberg O. Aksglaede. Radiology of the Pharynx and the Esophagus. Heidelberg: Springer; 2004.
Schmidt T, Lordick F, Herrmann K, Ott K. Value of functional imaging by PET in esophageal cancer. J Natl Compr Canc Netw. 2015;13(2):239–47.
Swager A, Curvers WL, Bergman JJ. Diagnosis by endoscopy and advanced imaging. Best Pract Res Clin Gastroenterol. 2015;29(1):97–111.
Yip C, Cook GJ, Landau DB, Davies A, Goh V. Performance of different imaging modalities in assessment of response to neoadjuvant therapy in primary esophageal cancer. Dis Esophagus. 2015 (Epub ahead of print).