

The thoracic esophagus: sectional anatomy and radiosurgical applications

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Summary. The relationships of a tumor of the thoracic esophagus to the adjacent mediastinal structures are currently studied by means of computed tomography (CT), magnetic resonance imaging (MRI) and, more recently, by echoendoscopy. However, the assessment of axial mediastinal CT and of MRI in the coronal and sagittal planes calls for some degree of experience. To further this training a sectional anatomy is proposed in correlation with imaging of the thoracic esophagus and the posterior mediastinum. Ten fresh subjects whose vascular networks had been previously injected with colored resin were sectioned along the three planes of space after positioning under CT monitoring. The axial sections were compared with the CT images made with a GE 9800 Quick scanner. Three frontal and sagittal sections were compared with the MRI images made with a

GE Signa apparatus using a high magnetic field. The relations of the esophagus were studied at three levels : the supra-azygo-aortic segment, where it is related to the left subclavian artery; the inter-azygo-aortic segment, where access to the esophagus is barred on the left by the aortic arch and on the right by the arch of the azygos vein, section of which provides ample access; and the sub-azygo-aortic segment, where the esophagus passes behind the left main bronchus and to the right of the descending aorta, two organs whose invasion contraindicates excision of a tumor of the esophagus but is difficult to assess by current thoracic imaging techniques. The esophagus then descends behind the left atrium; the investigation of the kinetics of the heart cavities by transesophageal echocardiography is an application of this anatomic relationship. These anatomic sections should form useful teaching aids for the study of CT and MR images by radiologists and should help surgeons to assess the possibilities of tumor excision.

L'oesophage thoracique : anatomie sectionnelle et applications radiochirurgicales

Résumé. Les rapports d'une tumeur de l'oesophage thoracique avec les structures médiastinales voisines sont actuellement étudiés par tomodensitométrie (TDM), résonance magnétique (IRM) et plus récemment par écho-endoscopie. Or, l'analyse d'une TDM médiastinale axiale et d'une IRM en plans frontaux et sagittaux nécessite un certain apprentissage. C'est dans ce but didactique qu'est ici proposée une anatomie sectionnelle avec sa corrélation en imagerie concernant l'oesophage thoracique et le médiastin postérieur. Dix sujets frais dont les réseaux vasculaires ont été préalablement injectés de résine colorée ont été sectionnés selon les trois plans de l'espace après positionnement sous contrôle TDM. Les coupes axiales ont été comparées aux images TDM faites sur scanner GE 9800 Quick. Les coupes frontales et sagittales ont été comparées

à une imagerie par résonance magnétique avec un appareil signa GE à haut champ magnétique. Les rapports de l'oesophage sont étudiés à trois étages: segment sus-azygo aortique, où il est en rapport avec l'a. sub-clavière gauche et le conduit thoracique ; segment inter-azygo aortique, où l'accès à l'oesophage est barré à gauche par l'arc aortique et à droite par la crosse de la v. azygos dont la section ouvre une large voie d'abord ; segment sous-azygo aortique enfin, où l'oesophage se place derrière la bronche principale gauche et à droite de l'aorte descendante, deux organes dont l'envahissement, difficilement apprécié par l'imagerie thoracique actuelle, contre-indique une chirurgie d'exérèse d'une tumeur de l'oesophage. L'oesophage descend ensuite et l'écho-cardiographie trans-oesophagienne permettant d'explorer la cinétique des cavités cardiaques est une application de ce rapport anatomique. Ces coupes anatomiques doivent servir de documents pédagogiques pour l'analyse de l'imagerie TDM, IRM par les radiologues et l'appréciation de l'extirpabilité d'une tumeur par les chirurgiens.

Key words : Esophagus — Descending aorta — Computed tomography (CT) — Magnetic resonance imaging (MRI) — Serial anatomic sections

Two organs with a vertical course occupy the center of the posterior mediastinum : the esophagus and the descending thoracic aorta. While the aorta traverses the entire mediastinum, the esophagus remains within the posterior mediastinum from the upper aperture of the thorax to its diaphragmatic hiatus. The esophageal mucosa can be studied by alimentary endoscopy and the position and extent of esophageal mucosal lesions by barium transit; currently, the relationships of these lesions with the adjacent mediastinal structures are assessed by CT and MRI and, more recently, by echoendoscopy. However, the use of a mediastinal scanner or an MRI apparatus calls for some training, and it is with this purpose in view that we here put forward a radio-anatomic study of the esophagus and posterior mediastinum.

Material and methods

Ten fresh subjects obtained from the anatomy department of the Faculté Biomédicale des Saints-Pères and the school of surgery of Fer à Moulin were processed at the anatomy department of the Faculté Necker Enfants Malades according to the following protocol.

Anatomy

The femoral artery and vein were accessed and cannulated in the femoral triangle, then the axillary artery and vein, and finally the common carotid artery and internal jugular vein in the sternocleidomastoid region. The arterial and venous beds were irrigated with physiological saline, and then both systems were injected with a mixture of a polyester resin (Ambrex®) with an accelerator, a catalyst and a colorant - red for the arteries and blue for the veins. The fresh subjects were then frozen at -30°C after having taken care to inflate the lungs in hyperpressure via a tracheostomy cannula to fix them to the parietes. The torsos of the subjects were then separated and positioned under CT monitoring in the military teaching hospital of Val de Grâce. Once the plane of section had been exactly identified, the tor-

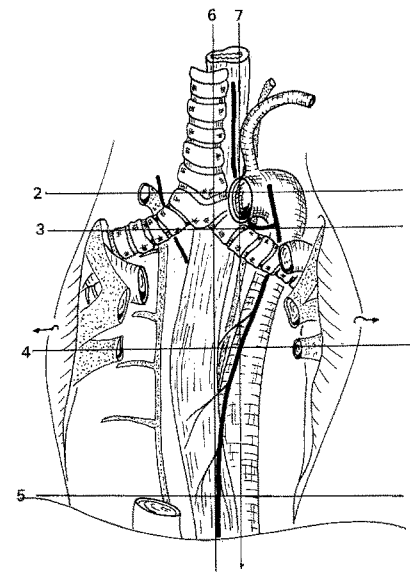


Fig. 1
Posterior mediastinum (anterior view) : levels of axial and sagittal sections and nos. of corresponding figures

Médiastin postérieur (vue antérieure) : niveaux des coupes axiales et sagittales - N° des figures

so was embedded in polyurethane foam. After a further period of freezing the subjects were sectioned at 5 mm intervals in the three spatial planes as defined by the radiologist. These different sections were washed, photographed and compared to the data obtained by imaging.

Imaging

The imaging of the different anatomic specimens was performed at the Val de Grâce institute before sectioning, but also on 10 live subjects free of esophageal pathology reported here. The CT images in the axial plane were made with a Quick GE 9800 scanner after injection of a contrast medium into a mediastinal window. The MRI study was made with a Signa apparatus (General Electric) using a high magnetic field (1.5 Testa) in T1-weighted spin echo sequences in cardiac syn-

chronisation. The sections were made in three planes: axial, frontal and sagittal. 8 frontal, 8 sagittal and 12 axial sections were kept for study.

Results

The principal sections correlating the anatomy and the imaging are co-presented in the attached double plate (Figs. 2 to 9).

Axial sections

T4 is the level of the vascular arches (Fig. 2) : the arch of the aorta on the left, the arch of the azygos vein on the right. The esophagus is close to the postero-right aspect of the aortic arch, behind the trachea.

At T6 the esophagus is situated behind the left main bronchus and to the right of the descending aorta (Fig. 3).

The section through T7 (Fig. 4) shows an anterior mediastinum entirely occupied by the cardiac mass, whose most posterior cavity is that of the left atrium. Here it receives the left inferior pulmonary vein. The esophagus descends behind the left atrium and the pulmonary veins, from which it is separated by the pericardial sac of Haller. In the MR image the posterior mediastinum is reduced, with the esophagus at its center and the descending aorta on its left (Fig. 4b). At T9 (Fig. 5) the inferior vena cava empties into the inferior wall of the right atrium. This is also the atrial opening of the coronary venous sinus in the coronary sulcus. The esophagus lies behind the coronary sinus and in front of the thoracic duct .

Sagittal sections

Two sagittal sections are useful in describing the thoracic esophagus :

- the sagittal section at 5 mm to the left of the midline (Fig. 6) shows

the trachea obliquely below and behind. The tracheobronchial plane separates the wide anterior mediastinum containing the cardiac mass between T7 and T9 below the great vessels from the very narrow posterior mediastinum centered on the esophagus. In MRI, the esophagus is followed throughout its extent behind the trachea, then behind the left atrium where it is overlaid by the right pulmonary artery, to its diaphragmatic hiatus (Fig. 6b).

- the sagittal section 15 mm to the left of the midline (Fig. 7) is of cardinal importance because it passes through the esophageal lumen and shows, backing on to its anterior wall from above downwards, the descending aorta just after the origin of the left subclavian a. and then the left main bronchus.

Coronal sections

The coronal sections involving the posterior mediastinum have been selected from behind forwards :

- behind the esophagus, the dorsal vertebral column is flanked on its left by the descending aorta and on its right by the azygos v., receiving the intercostal veins (Fig. 8). MRI shows the esophageal lumen lying between the azygos v. ascending to its suprapedicular arch on the right and the descending aorta on the left (Fig. 8b)

- the section passing through the esophageal lumen (Fig. 9a) involves the left pulmonary pedicle. Three levels of esophageal relations are illustrated here : above, the esophagus lies between the aortic isthmus and the azygos arch; lower down, it is behind the left main bronchus; and finally it lies against the left atrium, which receives the left inferior pulmonary vein.

The MRI section is more anterior, in the tracheal plane (Fig. 9b). It shows the posterior part of the aortic arch, giving off the left sub-

clavian a., which ascends to the left of the esophagus.

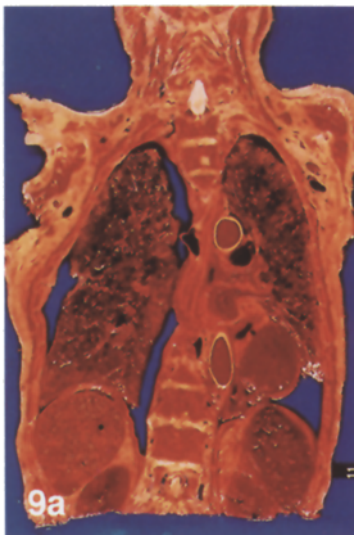
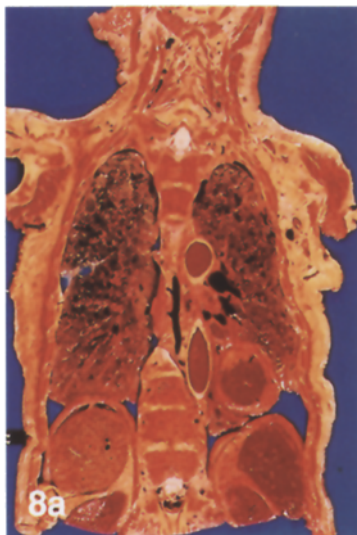
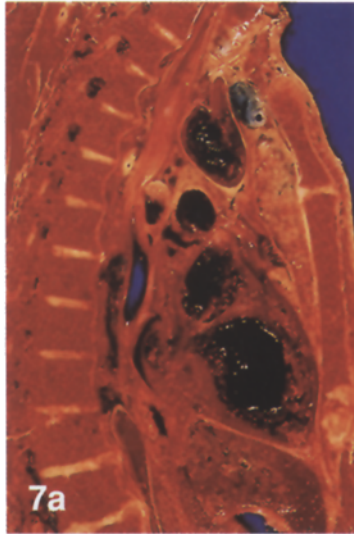
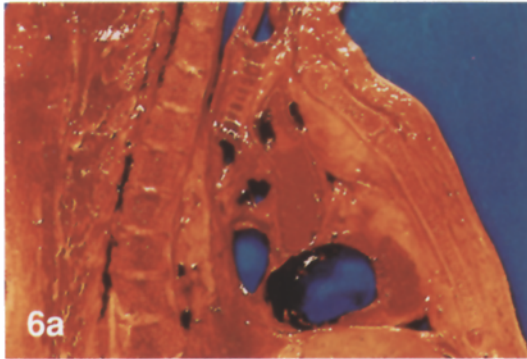
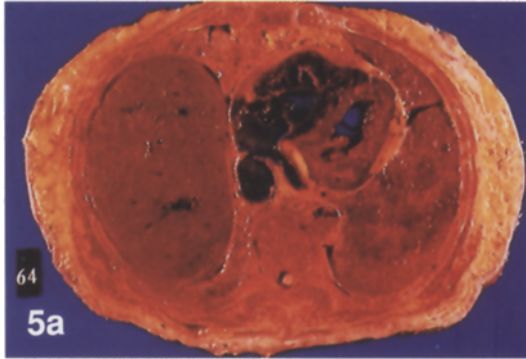
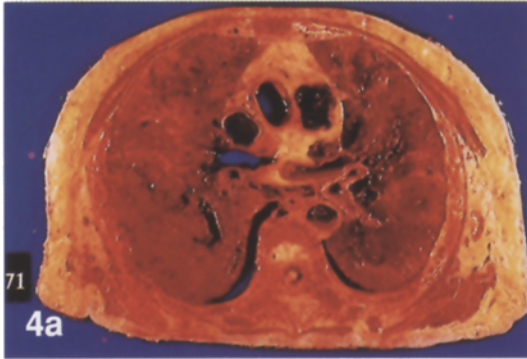
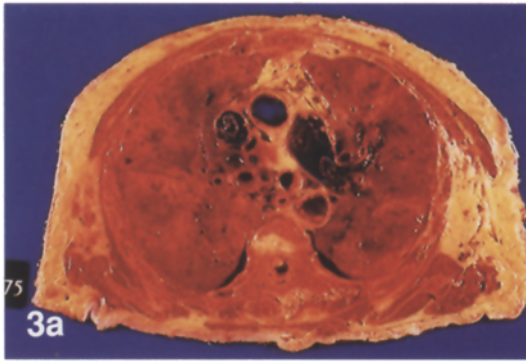
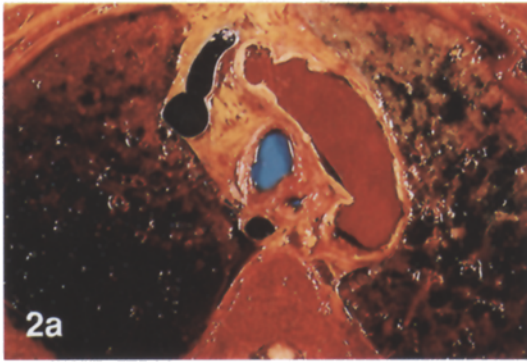
Discussion

Surgical anatomy of the thoracic esophagus

Satisfactory assessment of modern thoracic imaging requires some degree of training and these anatomic sections should serve an instructional purpose. The vertical esophagus is at the center of the posterior mediastinum, but classically it has a bayonet-shaped course, first obliquely downward and to the left, then displaced to the right by the aortic arch, and then vertical once more as it passes to its hiatus (Fig. 1).

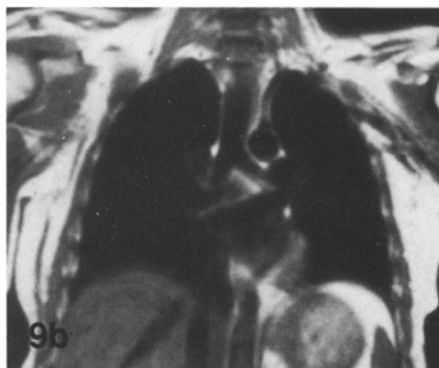
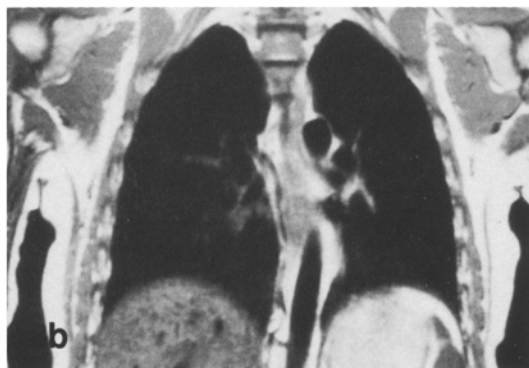
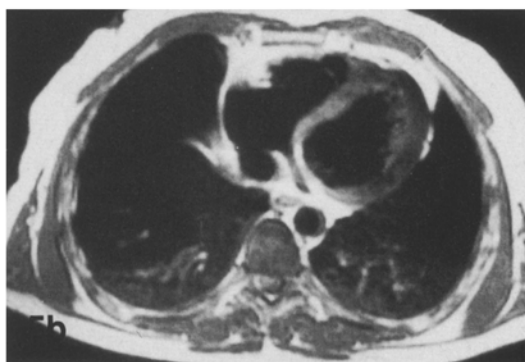
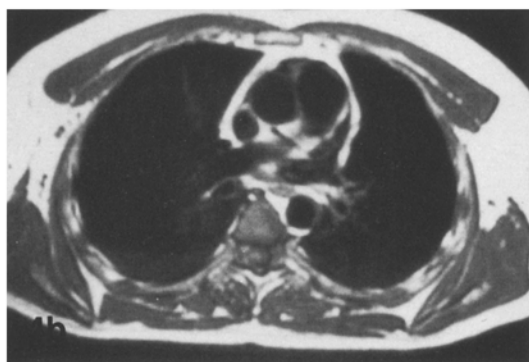
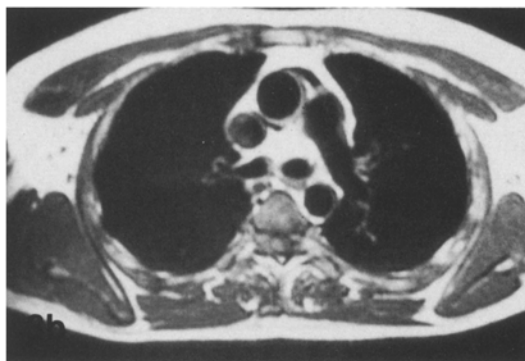
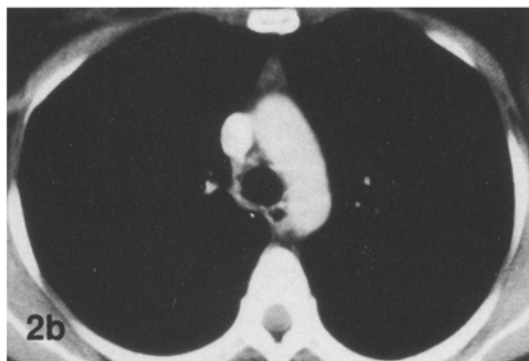
At the superior aperture of the thorax, opposite T2, the esophagus is within the visceral sheath behind the trachea, which it overlaps on the left. The thoracic duct ascends on its left. The recurrent laryngeal nerve ascends in the left esophageo-tracheal angle accompanied by its lymphatic chain. In front, the infrahyoid muscles are attached behind the sterno-costo-clavicular joints. The two brachiocephalic venous trunks and the three supraortic arterial trunks are distributed between the two. At this level, the esophagus is immediately to the right of the left subclavian a. (Figs. 7b and 9b).

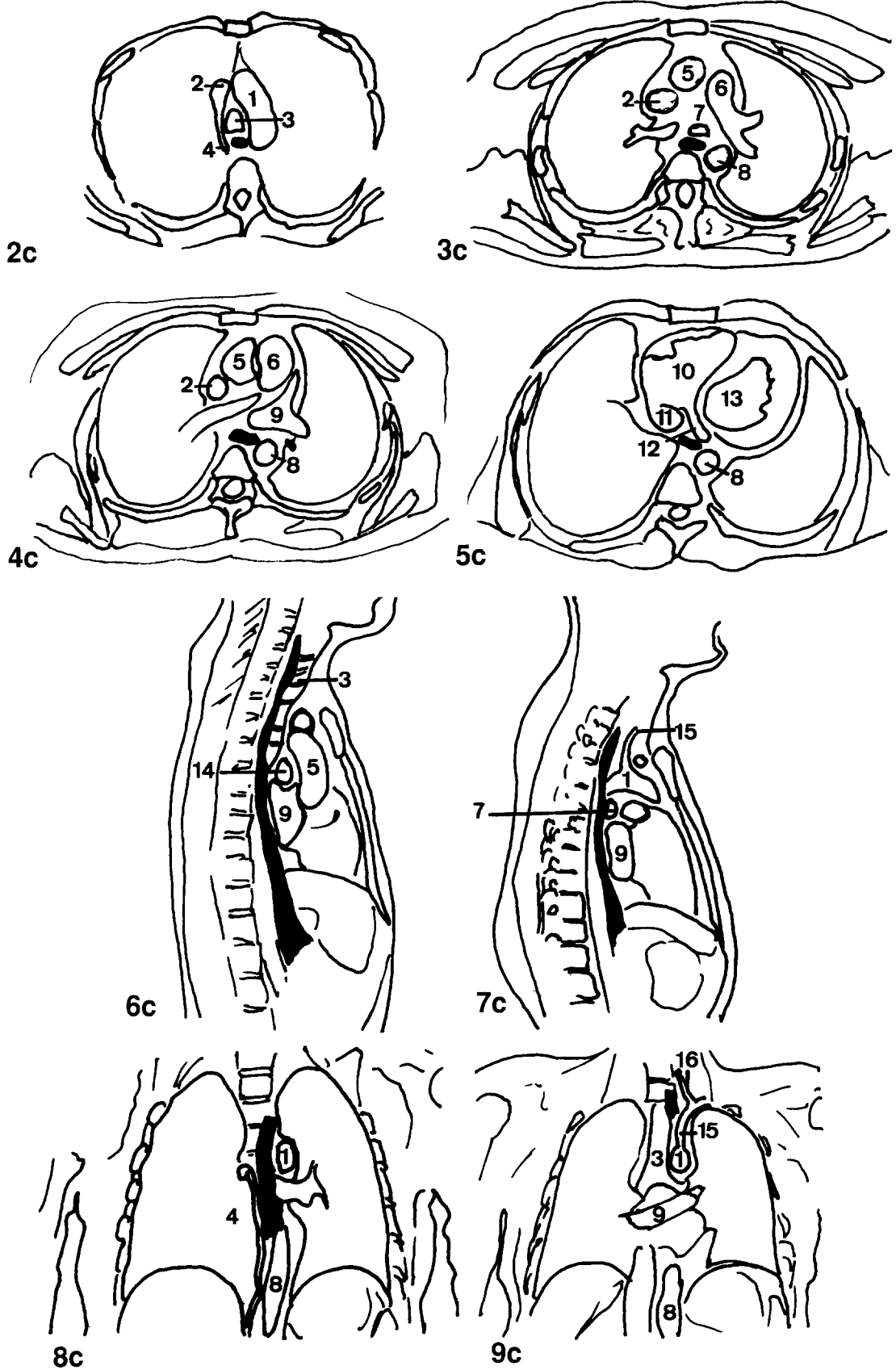
At T4 the esophagus is behind and to the left of the trachea. The thoracic duct ascends behind it and to its left and here is the origin of the descending aorta. Surgical access to the middle third of the esophagus is barred on the left by the aortic arch (Fig. 2b), so that access is usually from the right side. Behind the trachea, section of the arch of the azygos v. and of its intercostal affluents opens the mediastinal pleura over the esophagus.



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←Figs. 2-9

2 Axial section at T4: **a** anatomic section **b** corresponding CT section 3 Axial section at T6: **a** anatomic section **b** corresponding MRI section 4 Axial section at T7: **a** anatomic section **b** corresponding MRI section 5 Axial section at T9: **a** anatomic section **b** corresponding MRI section 6 Sagittal section 5 mm to left of midline: **a** anatomic section **b** corresponding MRI section 7 Sagittal section 15 mm to left of midline: **a** anatomic section **b** corresponding MRI section 8 Coronal section, posterior inter-azygo-aortic plane : **a** anatomic section, plane of esophageal lumen **b** corresponding MRI section 9 Coronal section, plane of esophageal lumen : **a** anatomic section **b** corresponding MRI section in middle plane showing tracheal bifurcation 1 aortic arch 2 superior vena cava 3 trachea 4 azygos v. 5 ascending aorta 6 pulmonary trunk 7 left main bronchus 8 descending aorta 9 left atrium (and pulmonary vv.) 10 right atrium 11 inferior vena cava 12 coronary sinus 13 left ventricle 14 right pulmonary a. 15 left subclavian a. 16 left vertebral a.

2 Coupe axiale en T4 : **a** coupe anatomique **b** TDM axiale 3 Coupe axiale en T6 **a** coupe anatomique **b** IRM axiale en T6 4 Coupe axiale en T7: **a** coupe anatomique **b** IRM axiale en T7 5 Coupe axiale en T9 **a** coupe anatomique **b** IRM axiale en T9 6 Coupe sagittale à 5 mm à gauche de la ligne médiane **a** coupe anatomique **b** IRM sagittale à 5 mm à gauche de la ligne médiane 7 Coupe sagittale à 15 mm à gauche de la ligne médiane **a** coupe anatomique **b** IRM sagittale à 15 mm à gauche de la ligne médiane 8 Coupe frontale - Plan postérieur interazygo-aortique **a** coupe anatomique **b** IRM frontale - plan interazygo-aortique 9 Coupe frontale - Plan de la lumière oesophagienne **a** coupe anatomique **b** IRM frontale - plan moyen - bifurcation trachéale 1 arc de l'aorte 2 VCS 3 trachée 4 v. azygos 5 aorte ascendante 6 tronc pulmonaire 7 bronche principale gauche 8 aorte descendante 9 oreillette gauche (et vv. pulmonaires 10 oreillette droite 11 VCI 12 sinus coronaire 13 ventricule gauche 14 a. pulmonaire droite 15 a. sub-clavière gauche 16 a. vertébrale gauche

At T5, the tracheal bifurcation is slightly deviated to the right by the aortic arch, such that the esophagus passes behind the left main bronchus (Figs. 3, 7a, 9).

It is at T6 that it is necessary to assess the relations of a tumor of the middle third of the esophagus with the organs closest to it: the left main bronchus and descending aorta. The normal esophagus is visible throughout its length (Fig. 7b). It is separated from these two mediastinal structures by a fatty plane [4]. The disappearance of this fatty plane between an esophageal tumor and the adjacent structures is the first sign of direct invasion [9]. The criteria of involvement of the aorta have been defined by Picus [11] : on the axial sections the aorta is represented as a complete 360° circle. When the contact of the tumor with the aorta corresponds to an angle of 90° invasion is certain; if this angle does not exceed 45° the aorta is not invaded; and between 45° and 90° CT is unable to specify involvement of the aorta. However, the disappearance of this fatty border may be no more than the outcome of the associated malnutrition [4], which renders interpretation of these images difficult.

T7 and T8 are the so-called "cardiac" vertebrae. The most posterior cardiac cavity is the left atrium, which receives the pulmonary veins. The esophagus is separated from the left atrium only by the pericardial sac of Haller, which insinuates itself between the openings of the right and left pulmonary vv. It is clear that the insertion of an ultrasonic probe into the esophagus allows investigation of the kinetics of the cardiac cavities across the esophageal wall (trans-esophageal echocardiography).

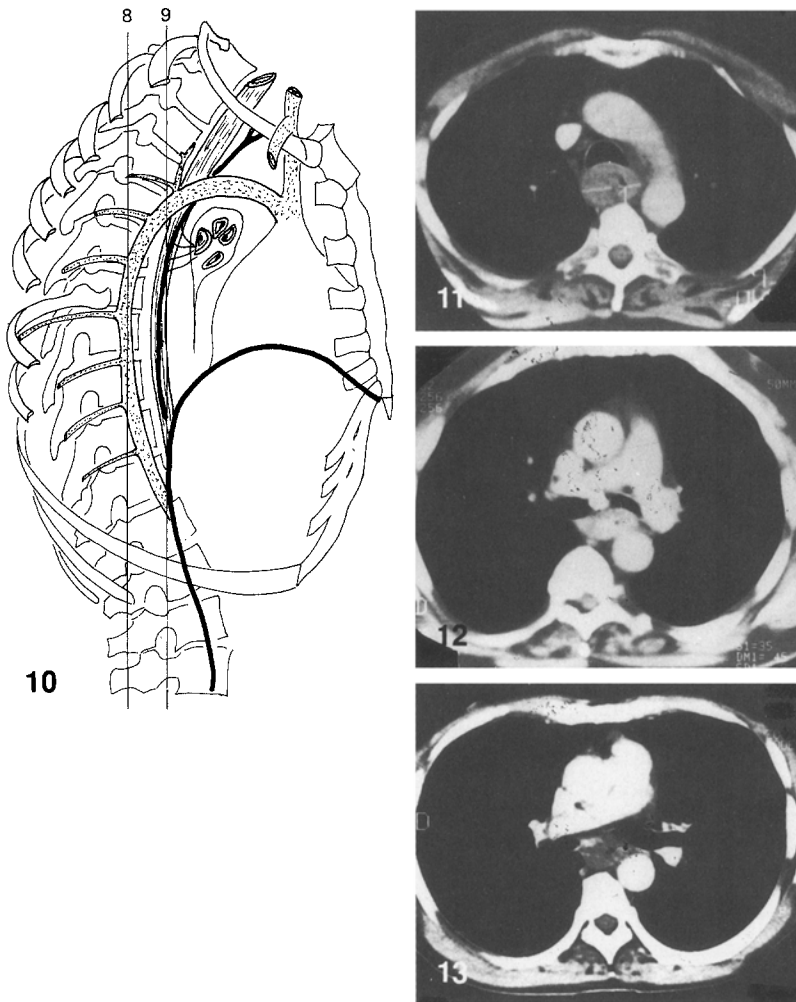
The left inferior pulmonary v. constitutes the boundary between the middle and lower thirds of the esophagus. This is the upper limit of access to the esophagus by left tho-

racotomy, since above this level access is barred by the left pulmonary pedicle and the aorta; hence the preference for right thoracotomy.

At T9 the esophagus is situated between the thoracic duct behind and the intrapericardial coronary venous sinus, in the intersection of the sulci, in front (Fig. 5b). Here, the thoracic duct lies between the descending aorta on the left and the azygos v. on the right, and it is here that the duct must be ligated during the mediastinectomy accompanying ablation of an esophageal tumor to avoid a postoperative chylothorax [5].

The esophagus traverses the diaphragm opposite T10 through a muscular orifice formed by the right and left crura. The right crus is situated between the inferior vena cava, which here is still abdominal, retrohepatic and behind the caudate lobe, and the descending aorta, which is still thoracic in the posterior inframediastinal space.

The surgical excision of a cancer of the middle third of the esophagus is performed via a right thoracotomy. The collapsed lung is retracted forward, and section of the mediastinal pleura and of the arch of the azygos v. provides access to the esophagus (Fig.10). The right vagus nerve is identified and divided below its bronchial efferents, preservation of which facilitates postoperative ventilation. The esophagus must then be freed below from the pericardium in front and from the descending aorta, which gives off one or more esophageal arteries, the thoracic duct being ligated between the aorta and the azygos v. Above, the tumor must be separated from the tracheobronchial tree, in particular from the main left bronchus, with an eradication of the lymph nodes that includes the left recurrent chain behind the aortic arch and in the left esophageo-tracheal angle on the left, and ascen-



Figs. 10-13

10 Right lateral view of mediastinum (numbers are those of figures of corresponding coronal sections): the right vagus n. is shown alongside the esophagus with its bronchial efferents **11** CT of an esophageal tumor molded to the posterior aspect of the tracheal bifurcation: excision impossible **12** CT of a tumor bulging into the left main bronchus: Akiyama procedure performed **13** No local regional extension is shown by CT, but at operation there was adhesion to the left bronchial membrane and excision was impossible

10 Vue latérale droite du médiastin (niveaux des coupes frontales. N° des figures). Le nerf vague droit est représenté le long de l'oesophage, avec ses efférences bronchiques **11** TDM d'une tumeur oesophagienne moulant la face postérieure de la bifurcation trachéale. Exérèse impossible **12** TDM d'une tumeur bombant sur la bronche souche gauche. Akiyama effectuée **13** Absence d'extension loco-régionale visible en TDM. Adhérence à la membraneuse bronchique gauche : exérèse impossible

ding as far as the node of the right recurrent nerve below the right subclavian a. on the right [7].

Assessment of the value of CT in the preoperative investigation of a cancer of the esophagus is still tricky. Here, for example, are the findings in 3 patients with epidermoid cancer of the middle third of the esophagus in which the radiolo-

gic interpretation was unsatisfactory. Figure 11 relates to a man aged 52 with a tumor well away from the aortic arch and the descending aorta, but molded to the posterior aspect of the tracheal bifurcation without radiologic evidence of invasion. At right thoracotomy it was impossible to remove the tumor because of invasion of the

posterior aspect of the trachea which had not been revealed by either bronchial fiberoscopy or by CT. Figure 12 relates to a man aged 70 where the tumor gives the left main bronchus a very convex appearance with absence of the fatty boundary between the tumoral mass and the bronchial wall. At operation there was a plane of cleavage which allowed performance of an esophagectomy with gastroplasty by Akiyama's technique. Finally, Fig. 13 relates to a man aged 47 where CT suggested the absence of visible loco-regional extension because of an interface with the antero-right wall of the thoracic aorta and with the main left bronchus. Nonetheless, excision proved impossible because of adhesion of the tumor to the membranous left bronchus over about 1 cm².

A study of the more important work regarding assessment of the prognostic value of preoperative imaging of cancer of the thoracic esophagus reveals that CT is not the best means of defining inoperability. This is because fiberoscopy and barium transit are equally reliable regarding the level of the upper limit of the tumor [1, 6], while bronchial fiberoscopy is adequate as regards tracheobronchial invasion or bulging [3]. Moreover, CT has been shown in prospective and blind studies to be inadequate concerning the two real problems, which are the connexions with the aorta and mediastinal or celiac adenopathies [4, 10]. Less attention has been given to assessment of the value of MRI, but at the present time it does not seem to provide significantly improved information as regards either connections with the aorta or nodal invasion.

The risk is in fact twofold : that of operating on a lesion adherent to the aorta or the tracheobronchial tree (here the lack of sensitivity is around 10%) and, in particular, that of withholding curative intervention

because of overestimation of the local extension of the growth, a risk estimated at 25% by most authors [4]. In the present state of research, CT is needless if the cancer is judged operable and excision possible by classical assessment. Its value would seem related to assessment of the tumoral response to treatment of an advanced cancer by radio-chemotherapy.

Though CT does not seem to have stood the test of time, MRI may prove useful in the future, but it is a recent technique and requires standardisation of the imaging criteria and refinements in technique. This means that radiologists and surgeons must become accustomed to the reading of these new images. Apart from the value of transesophageal ultrasonography in the kinetic study of the cardiac cavities, the anatomic sections illustrate the present prognostic value of esophageal echo-endoscopy in studying the connexions of an esophageal tumor

with the adjacent mediastinal structures : the trachea, the main left bronchus and the descending thoracic aorta [10, 13].

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