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A new concept of the anatomy of the thoracic oesophagus: the meso-oesophagus. Observational study during thoracoscopic esophagectomy

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Abstract
Background During thoracoscopic oesophageal surgery, we observed not previously described fascia-like structures. Description of similar structures in rectal cancer surgery was of paramount importance in improving the quality of resection. Therefore, we aimed to describe a new comprehensive concept of the surgical anatomy of the thoracic oesophagus with definition of the meso-oesophagus.
Methods We retrospectively evaluated 35 consecutive unedited videos of thoracoscopic oesophageal resections for cancer, to determine the surgical anatomy of the oesophageal fascia's vessels and lymphatic drainage. The resulting concept was validated in a prospective study, including 20 patients at three different centres. Additional confirmation was sought by a histologic study of a cadaver's thorax.
Results A thin layer of connective tissue around the infracarinal oesophagus, involving the lymph nodes at the level of the carina, was observed during thoracoscopic esophagectomy in 32 of the 35 patients included in the retrospective study and in 19 of the 20 patients included in the prospective study. A thick fascia-like structure from the upper thoracic aperture to the lower thoracic aperture was visualized in all patients. This fascia is encountered between the descending aorta and left aspect of the infracarinal oesophagus. Above the carina it expands on both sides of the oesophagus to lateral mediastinal structures. This fascia contains oesophageal vessels, lymph vessels and nodes and nerves. The histologic study confirmed these findings.
Conclusions Here we described the concept of the "meso-oesophagus". Applying the description of the meso-oesophagus will create a better understanding of the oesophageal anatomy, leading to more adequate and reproducible surgery.

Keywords Oesophagus · Meso-oesophagus · Anatomy · Surgical resection · Thoracoscopy

Since the first modern description of the oesophagus in 1543 by Andreas Vesalius in Book V of the *Humani Corporis Fabrica* [1], multiple and succeeding anatomists have until recent date, portrayed the oesophagus anatomy by relying on cadaver studies. Thereby describing vessels from and to the oesophagus, nerves and plexuses and by portraying the extensive net of lymph vessels and nodes [2–11]. Yet, present-day surgeons called to treat oesophageal diseases, especially cancer, may still find such an anatomy of the oesophagus incomplete.

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Currently, the oesophagus is described as a slender muscular tube, embedded in loose connective tissue in the posterior mediastinum where it is encircled by important mediastinal structures, such as the heart, aorta and trachea. Based on in vivo observations, a new concept of the tissue in which the thoracic oesophagus is embedded is described. During more than one-hundred thoracoscopic oesophageal resections for cancer [12], a thick vascular fascia between the aorta and the left aspect of the oesophagus was repeatedly observed, which we called the meso-oesophagus, spreading around the oesophagus. This fascia contained the vessels from the aorta to the oesophagus, lymph vessels and nodes and nerves. These observations prompted us to perform a prospective study with in vivo imaging and a histologic study to evaluate this concept, entailing the description of the anatomical structures and planes of the oesophagus. We especially focussed on the study of this fascia, its extensions and relation with the oesophagus and the thoracic aorta.

Materials and methods

Retrospective study

Two experienced surgeons (MAC and DvdP) evaluated 35 consecutive unedited videos of thoracoscopic oesophageal resections performed at the VU medical centre in Amsterdam to determine the surgical anatomy of the oesophageal fascias, vessels and lymphatic drainage. The videos involved 35 patients diagnosed with thoracic oesophageal cancer.

All patients were treated by neoadjuvant chemoradiotherapy [13], followed by en bloc thoracoscopic oesophagolymphadenectomy 6 weeks later, as described previously [12]. After single-lumen tracheal intubation, the patient is placed in prone position with abduction of both arms to expand the space between the spine and scapulae. Open thoracoscopy at the point of the scapula is then performed, creating intrathoracic insufflation with 8 mm Hg. In this way, the oesophageal area is completely envisioned without any interference from the right lung. Three other trocars are introduced along the inner aspect of the scapula. Dissection commences after division of the pulmonary ligament with opening of the pleura along the right lung. From the right bronchus on, the pleura is opened in the direction of the azygos vein arch and from there to the apex of the thoracic cavity. The oesophagus and all peri-oesophageal tissues are dissected free from the pericardial sac, right bronchus and carina, thus leaving the carina lymph nodes en bloc with the oesophagus.

The mediastinal pleura along the azygos vein is then opened up to the hiatus and there the oesophagus is dissected from the hiatus. The thoracic duct is next dissected between the aorta and azygos vein, maintained en bloc with the specimen and then adequately clipped to prevent any chyle leakage. The specimen is dissected from the antero-lateral aspect of the aorta and repositioning the oesophagus towards the right lung, the "fascia" between the aorta and oesophagus, from the aortic arch to the hiatus, is divided using sealing devices. In this way, vessels are divided from the aorta to the oesophagus, including the branches of the two bronchial arteries to the oesophagus. Bronchial branches to trachea and left bronchus are preserved. Once this fascia is divided, we can reach the pericardial sac, the left pulmonary vein and the left bronchus and subsequently the lymphadenectomy of the carina can be completed. Dissection now proceeds with the division of the arch of the azygos vein by means of endostapler and the dissection of the supracarinal oesophagus from the pars membranacea of the trachea can be completed.

After drainage of the thoracic cavity, the laparoscopic phase follows with a lymphadenectomy of the celiac trunk and a creation of the gastric tube. After retrieval of the specimen, the procedure is finalized with a cervical anastomosis performed between the gastric tube and oesophagus.

Prospective study

Subsequently, the proposed concept was prospectively studied in 20 thoracoscopic oesophageal resections for intrathoracic oesophageal cancer, located beneath the carina. With assistance of one of the senior authors (MAC) at all procedures, these were performed in three centres: VUmc in Amsterdam (15 procedures), AMC in Amsterdam (2 procedures) and Reinier de Graaf Groep in Delft (3 procedures).

Histologic study

Finally, to confirm in vivo findings, a cadaver's thorax was sliced in horizontal cross sections of one centimetre thickness. At two levels, above the aortic arch and at the level of the left atrium, tissue sections were stained according to Verhoef-von Giessen [14]. Purpose was to verify the existence of the in vivo observed organised layer of connective tissue located between the descending aorta and the oesophagus and around the oesophagus. Using this staining method, elastine fibres are stained in blue-black and the collagen fibrrs light red-pink [14].

Results

Retrospective and prospective included patients characteristics are depicted in Table 1. From all patients in the retrospective analysis, 27 (77 %) had adenocarcinoma and

Table 1 Patient characteristics

	Patients (*n*)	Adenocarcinoma	Squamous cell Carcinoma	Neoadjuvant therapy	Presence of Meso-oesophagus	Presence of peri-oesophageal fascia
Phase I retrospective	35	27 (77,1 %)	8 (22,9 %)	CROSS scheme	35 (100 %)	32 (91 %)
Phase II prospective	20	12 (60 %)	8 (40 %)	CROSS scheme	20 (100 %)	19 (95 %)

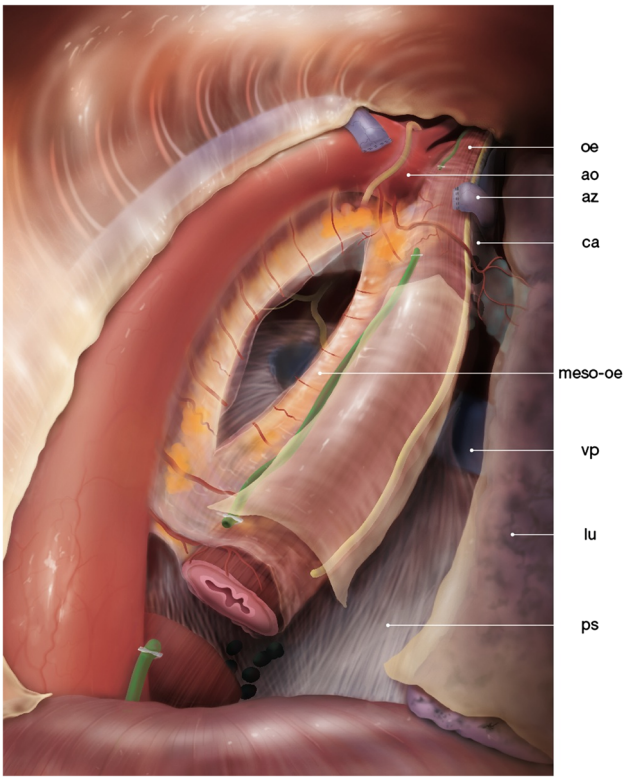

Illustration 1 Comprehensive concept of the oesophageal anatomy visualized from the prone position of the thorax. *ps* Pericard sac, *lu* right lung, *vp* right pulmonal vein, *ca*, carina and right bronchus *meso-oe* meso-oesophagus, *az* azygos vein; *ao* aorta, *oe* oesophagus

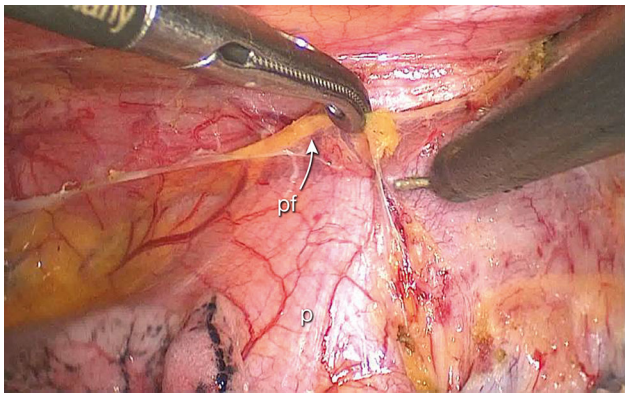

Fig. 1 The perimeso-oesophageal fascia being dissected from the pericardial sac. *pf* Perimesooesophageal fascia, *p* pericardial sac

8 (23 %) had squamous cell carcinoma. In the prospective analysis, 12 (60 %) of patients had adenocarcinoma and 8 (40 %) had squamous cell carcinoma. All patients received neoadjuvant chemoradiotherapy according to the CROSS scheme [13].

In thirty-two patients of the 35 (91 %) included in the retrospective analysis and in nineteen of the 20 (95 %) included in the prospective study, we observed a tiny layer of connective tissue spreading around the oesophagus over the whole infracarinal length (Fig. 1) involving the lymph nodes at the level of the right bronchus and carina (Fig. 2).

By retraction of the oesophagus from the aorta, a thick fascia-like structure is visualized from the upper thoracic aperture to the lower thoracic aperture in all patients (Fig. 3). This fascia is encountered first between the whole length of the descending aorta and the left aspect of the infracarinal oesophagus, later expanding on both sides of the supracarinal oesophagus to the lateral mediastinal structures. After division of the superficial part of this fascia, both the bronchial arteries, coming from the concavity of the aortic arch and between two and twenty oesophageal vessels coming from the direction of the thoracic aorta, are visualized between layers of this fascia (Fig. 4), thereby suggesting that the fascia is a bilayered structure. Moreover, lymphatics and left vagal nerves are also present. After division of this fascia (Fig. 5), the left

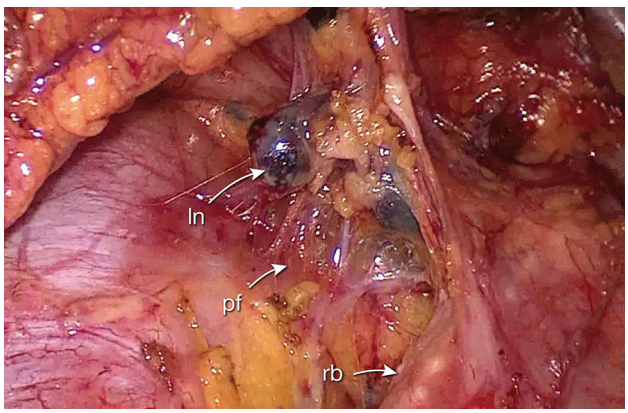

Fig. 2 Right bronchus lymph nodes. *ln* Lymphnode, *pf* perimeso-oesophageal fascia, *rb* right bronchus

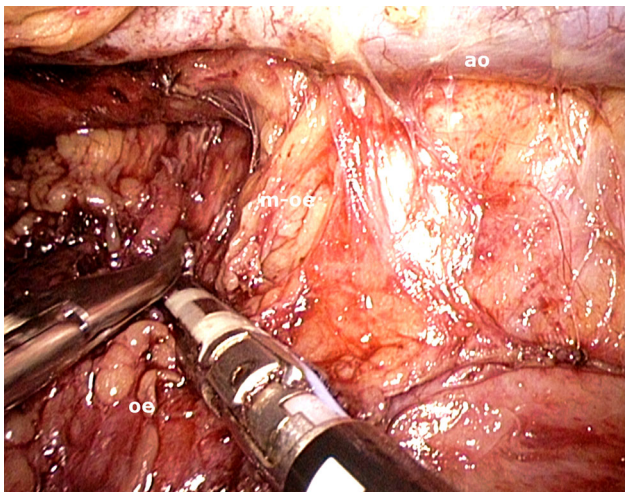

Fig. 3 The meso-oesophagus between aorta and oesophagus, partially divided. *m-oe* Mesooesophagus, *ao* aorta

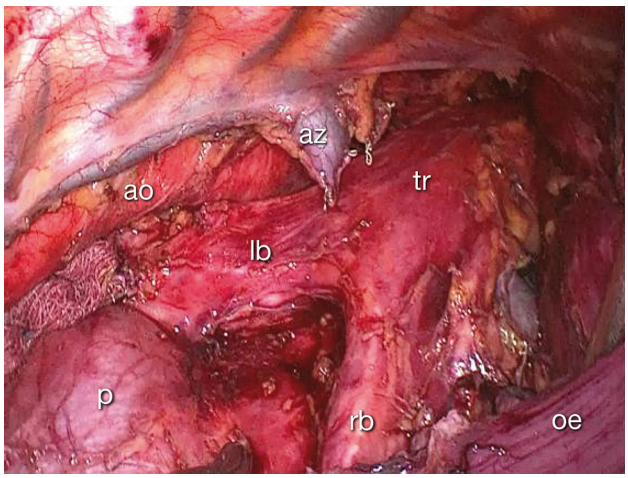

Fig. 6 Dissected mediastinum after division of the meso-oesophagus. *oe* Oesophagus, *rb* right bronchus, *tr* trachea, *lb* left bronchus, *az* azygos vein, *ao* aorta, *p* pericardial sac

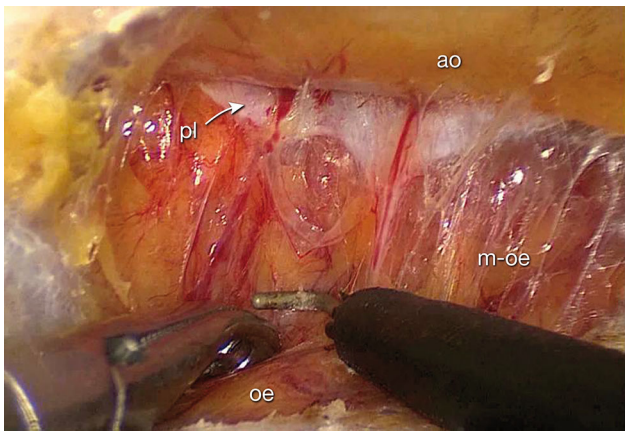

Fig. 4 The meso-oesophagus between aorta and oesophagus with multiple vessels. The left pleura is visualized. *pl* Pleura, *ao* aorta; *oe* oesophagus

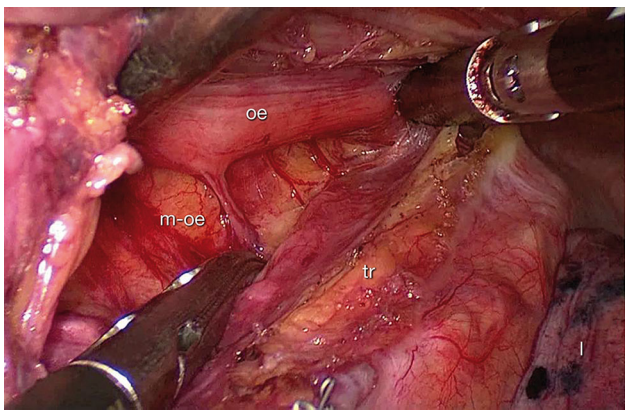

Fig. 7 Left sided para-oesophageal dissection above the level of the carina. The meso-oesophagus with multiple branches of the inferior thyroid arteries is visualised. *oe* oesophagus, *m-oe* Mesooesophagus, *tr* trachea, *l* lung

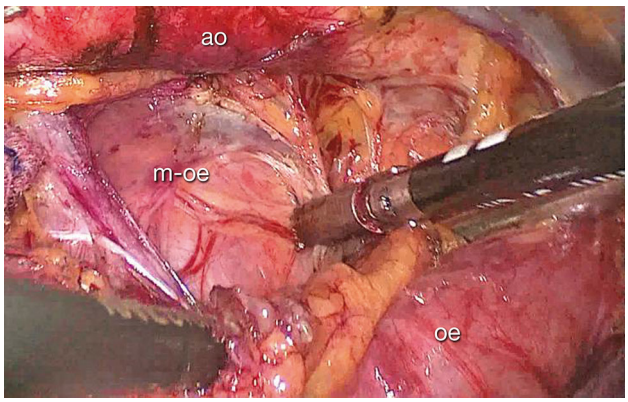

Fig. 5 Division of the meso-oesophagus at the proximal level of the descending aorta. *m-oe* Mesooesophagus, *oe* oesophagus

main bronchus, inferior left pulmonary vein, the pericardial sac and the most distal part of the contralateral pleura covering the left lung can be entirely visualized (Fig. 6). On the right side of the oesophagus, from the hiatus to the right bronchus, no vessels are encountered during the dissection. Between the level of the carina and the upper thoracic aperture, branches from bronchial arteries (and vagal nerves and lymphatics) and from both inferior thyroid arteries are encountered and divided on both sides of the oesophagus (Figs. 7 and 8).

The fascia that encloses vessels from the aorta (and inferior thyroid arteries) to the thoracic oesophagus, nerves and lymphatics, we named the meso-oesophagus. The tiny fascia surrounding the oesophagus we named the perimeso-oesophageal fascia. Both structures, the meso-oesophagus

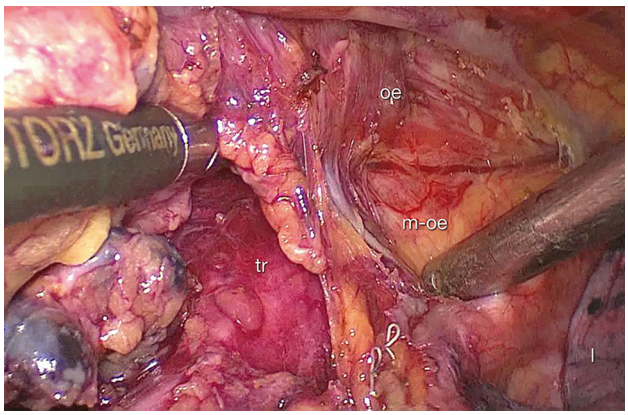

Fig. 8 Right sided para-oesophageal dissection above the carina. The meso-oesophagus with multiple branches of the inferior thyroid arteries is visualized. *oe* oesophagus, *m-oe* Meso-oesophagus, *tr* trachea, *l* lung

and the perimeso-oesophageal fascia, are found in continuity during "live" dissection. Illustration 1 offers the comprehensive anatomical picture of the concept.

This novel anatomical concept observed in vivo was confirmed by histologic findings. In microscopic sections just above the aortic arch, stained by the Verhoef-von Giessen method, a thin perimeso-oesophageal fascia surrounds the oesophagus and the trachea. At the level of the left atrium, the perimeso-oesophageal fascia surrounds the oesophagus and the meso-oesophagus is seen from the aorta to the left lateral aspect of the oesophagus with an oesophageal artery inside (Fig. 9).

Discussion

A comprehensive concept of the live surgical anatomy is necessary for ensuring anatomical accuracy as well as reproducible radical surgical resections for cancer. Heald and Ryall's definition of the total mesorectal excision (TME) of the mesorectum has been of paramount importance for obtaining a radical resection of rectal cancers by engaging an adequate surgical resection [15]. In the case of the oesophagus, having a clear concept regarding the resection margins and the relation with the thoracic aorta is important for standardizing the operative technique and optimizing the radicality of surgery.

Essential for realizing these goals is having accurate knowledge of the embryological development of the oesophagus, the respiratory tract and the mediastinum. Yet, in embryology, no complete agreement exists on how the early foregut differentiates into the respiratory tract and the intestinal tract. In particular, the formation of the early lung buds as well as the process of separation of trachea and oesophagus remains unclear [16, 17]. Metzger et al. studied this development using an electron microscope to scan chicken embryos. They illustrated the steps of the normal foregut development, which ultimately leads to the

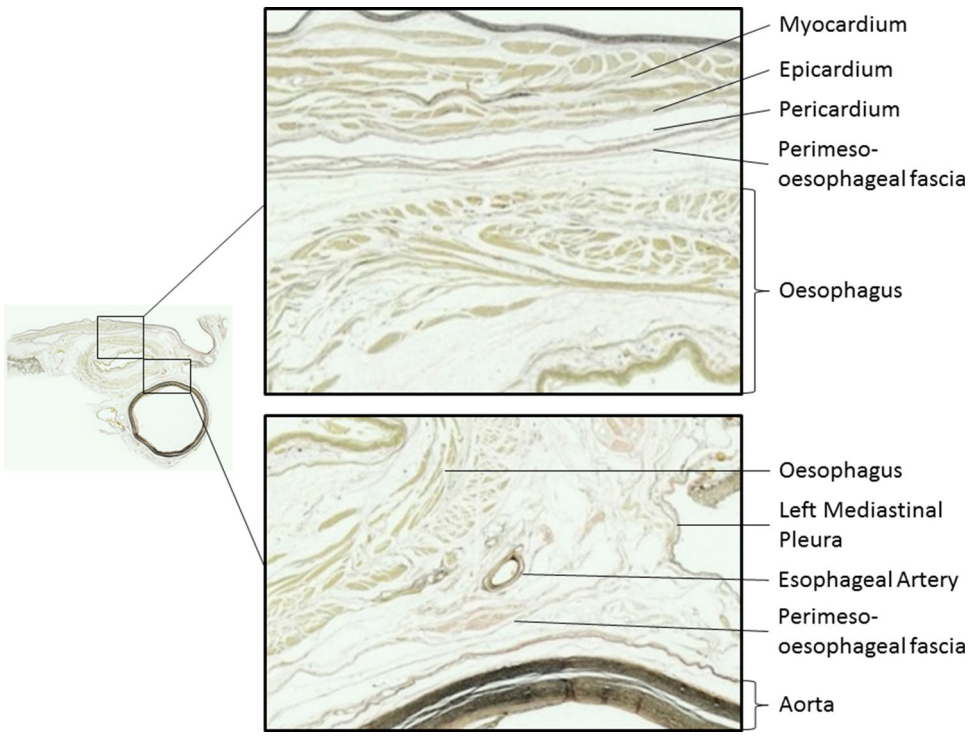

Fig. 9 Transverse section of the oesophagus and surrounding structures at the level of the left atrium. The mesooesophagus is seen from the aorta to the left lateral aspect of the oesophagus with an artery coursing inside. Also the thin perimeso-oesophageal fascia surrounding the esophagus is seen. Verhoef-von Giessen staining: elastine fibers are stained black, collagen fibers light red-pink

development of larynx and trachea on the one hand, and pharynx and oesophagus on the other hand [18].

In our present study, we have visualized two topographically related and previously undescribed anatomical structures, the perimeso-oesophageal fascia and the meso-oesophagus (Illustration 1), by use of live endoscopic high-definition imaging. Minimally invasive surgical dissection of the oesophagus by thoracoscopy permits us to observe "live" with magnification of the anatomy as it really is [19]. We have confirmed this by a histologic study. The neoadjuvant treatment with chemoradiotherapy, here used, has not affected the correct visualization of the meso-oesophagus in all patients and the perimeso-oesophageal fascia in more than 90 % of the patients included in this study. It is unclear why the perimeso-oesophageal fascia was not seen in a small proportion of the patients, hypothetical reasons may be the thinness of this layer or an effect of neoadjuvant radiotherapy.

The pertaining new comprehensive anatomical concept is unmistakeably significant. First, it defines the anatomical landmarks of the optimal resection by planes around the oesophagus. This is encircled from the carina to the hiatus by the perimeso-oesophageal fascia that needs to be dissected adequately from the mediastinum in order to obtain maximal circumferential resection margins. Second, it describes the meso-oesophagus through which vessels—variably in number and originating from the direction of the thoracic aorta and aortic arch—enter the left side of the thoracic oesophagus and well between two layers. The left and right bronchial arteries are also located in this meso-oesophagus and only the branches to the oesophagus have to be divided, preserving the vascular supply of the trachea and bronchi as much as possible [20]. At the level above the carina and on both sides, oesophageal vessels coming from bronchial arteries and from inferior thyroid arteries can be identified and divided. After division of this meso-oesophagus, the left main bronchus, the inferior left pulmonary vein, pericardial sac and contralateral left pleura can be visualized. It is possible that extension of the meso-oesophagus around the oesophagus may explain the existence of the perimeso-oesophageal fascia as shown in Illustration 1. These anatomical landmarks have proved reproducible, both in live operations and in a histologic study. Limitations of this study are that few patients without neoadjuvant chemoradiotherapy were included and that one approach only was used. Also the exact location of the lymph nodes in respect to the meso-oesophagus and perimeso-esophageal fascia was not investigated. These issues are now subject of further research.

We acknowledge that Matsubara et al. have used the term proximal meso-oesophagus (mesoesophagus) to define the distinct compartment where lymph nodes are located along the recurrent nerves, but not so as a layer in which vessels are going from the direction of the thoracic aorta to the oesophagus [21]. Marchand et al. described the mediastinal fascias in a cadaver study and observed in transverse section through the thorax a perivisceral fascia that around the oesophagus is prolonged around the right and left bronchi into the lung. This fascia will be occupied by connective tissue in which the bronchial vessels and lymphatics will lie [7]. Riddell et al. went on to use high-resolution MRI to evaluate the surgical anatomy of the oesophagus. They pinpointed in the lower part of the oesophagus a fascia attachment from the left lateral wall of the oesophagus to the aortic adventitia that continued laterally to the left parietal pleura. Moreover, they confirmed the presence of a fascial layer that passes posterior to the oesophagus within the posterior mediastinum and condensing bilaterally with the parietal pleura [22]. These observations describing the perivisceral fascia, as detected by Marchand and by Riddell, may be a part of the meso-oesophagus as observed and validated in our study. Moreover, Izon et al. defined in a retrospective morphometric study the resected "meso-oesophageal" tissue volume in oesophagectomy specimens [23]. They used the concept of meso-oesophagus as description of the peri-oesophageal tissues and adipose tissue to be resected. In order to define the quality of the resection, they confirmed the importance of the macroscopic morphometric aspect of the specimen.

Our definition of meso-oesophagus differs from the above in that it primarily defines the anatomical structure containing the vessels, nerves and lymphatics (from or to) the thoracic oesophagus. The term "meso" refers to mesentery; however, classical definition of mesentery refers to two sheets of peritoneum with blood vessels, lymph vessels and nerves in between. In special circumstances, like the mesentery of the descending colon, there is only one peritoneal sheet, given the other side is fused as the fascia of Toldt. In the case of the rectum, as is the case with the oesophagus, there is no peritoneal cover at all. Notwithstanding, we stress the importance of a radical resection along the anatomical defined planes in all kinds of oncological resections: high quality oncologic surgery necessitates adequate knowledge of these planes [24].

Differing, yet learning from previous anatomy studies [25], our definition of meso-oesophagus derived from live surgical endoscopic anatomy will improve understanding of the oesophageal anatomy, leading to a more adequate and reproducible surgical resection.

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