Supracarinal dissection of the oesophagus and lymphadenectomy by MIE

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Abstract: Since 1995, video-assisted thoracoscopic oesophagectomy (VATS), according the same surgical principles as the Japanese open surgery, has been completed in 700 patients with oesophageal cancer. Our indication for VATS is (I) no extensive pleural adhesion; (II) no contiguous tumor spread; (III) pulmonary function capable of sustaining single-lung ventilation, and (IV) non radiated patients. We use 4 ports around a 5 cm mini-thoracotomy on 5th intercostal space. We laid emphasis on utilizing magnifying effect of video (5 to 20 magnifications), obtained by positioning the camera at close vicinity to the dissection. Magnified view facilitates recognizing the fine layer structure of the mediastinum. The dissection should be performed following this layer structure just like open the page of a book. Tearing the layer makes the dissection irrational and cause unnecessary bleeding and invasiveness. The microanatomies we recognize during upper mediastinal dissection are (I) the most outer layer below the mediastinal pleura are branches from the vagus nerve and thoracic sympathetic trunk; (II) there is no vessel flow in the nerves or out, in the field of dissection; (III) the ideal layer of dissection along the nerve is exposing the epineurium; (IV) the strongest fixing structures in the mediastinum are the vagal nerves and nerves form thoracic sympathetic trunk; (V) the stump of thoracic duct shows particular appearance because of the intramural smooth muscle; (VI) the lymphonodes in the mediastinum are fixed strongly with nerves and gently with vessels; (VII) the aorta is covered with fine fibrous membrane consisting of branches form thoracic sympathetic trunk, etc. Magnified view shows the microstructure of the lymph node such as the afferent lymphatics penetrating the capsule and the hilum structure consisting the efferent lymphatics, artery, vein and nerve. The direction of the hilum of nodes is defined in each region. Therefore, understanding the hilum direction facilitates rational dissection. The hospital mortality was four patients (0.6%). The rate of regional control was 95%. The 5-year survival rates of the patients with pStage 0, 1, 2, 3, 4 were 92%, 88%, 69%, 52% and 24%, respectively, which were favorably compared with open surgery.

Keywords: Thoracoscopy; supracarinal dissection; microanatomy; oesophagectomy

Since the first report by Dallemagne with the patient in the left lateral position in 1991 and by Cuschieri in the prone position in 1992, minimally invasive oesophagectomy for cancer has gradually become popular and has been performed widely. After learning the technique, the previously undescribed fine anatomy, namely the microanatomy, became obvious under magnified view obtained by positioning the camera at close vicinity to the dissection and the thoracoscopic surgeon's knowledge of the layer structure in the mediastinum became profounder.

Table 1 Our indication for thoracoscopic oesophagectomy

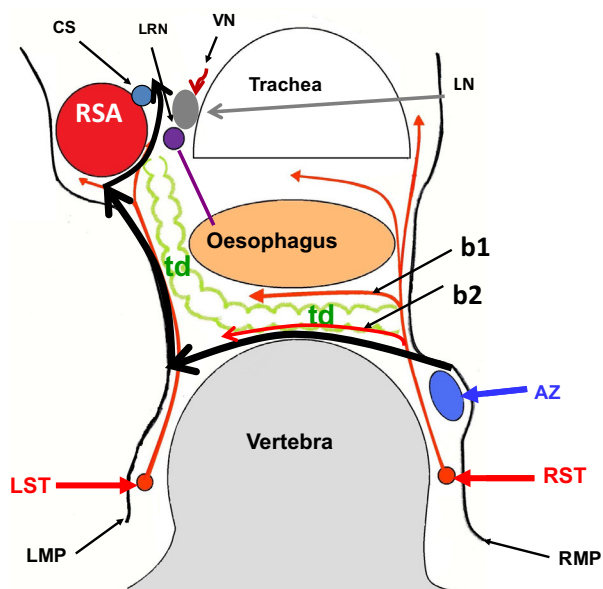| |
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| No extensive pleural adhesion preventing camera insertion |
| No contiguous tumor spread |
| Pulmonary function capable of sustaining single-lung ventilation |
| Radiation-naive patients |
| Patient's consent |

Figure 1 Illustration of the anatomy cranial to the aortic arch. Black heavy arrows indicate layers of dissection for total mobilization in the upper mediastinum. The sympathetic branches from the right trunk dominate over the left and encase the thoracic duct. RMP; right mediastinal pleura; LMP, left mediastinal pleura; RST, right trunk of the sympathetic nerve (b1 is the branch between the oesophagus and thoracic duct and the landmark of dissection when the thoracic duct is preserved; b2 is the Branche encasing the thoracic duct and is divided for total mediastinal mobilization); LST, left trunk of the sympathetic nerve; AZ, azygos vein, td; thoracic duct; RSA, right subclavian artery; CS, cardiac branches of the sympathetic nerve from the cervical ganglion; LRN, left recurrent nerve; LN, nodes along the left recurrent nerve; VN, vessels of the left recurrent nodes (commonly present in front of the node).

Reducing surgical trauma in the mediastinum by rational dissection along the anatomical layers is an important factor in minimally invasive surgery together with reducing the thoracic wound.

Three-field lymphadenectomy has been performed routinely since the mid-1980s in Japan (1), but the extent of lymph node dissection is still in discussion. According to the Efficacy Index [the incidence of metastasis to a region (%), multiplied by the 5-year survival rate (%) of patients with metastasis to that region and divided by 100] (2), the upper mediastinal nodes, such as the bilateral recurrent nodes and tracheobronchial nodes, should be dissected precisely, although dissection of these nodes requires substantial effort by surgeons and is associated with a risk of postoperative complications. The sensitivity for diagnosing the presence of metastasis in each lymph node station is low (3); therefore when retrieving nodes likely being metastasized, there is no excuse for omitting dissection of all nodes. In this chapter, the upper mediastinal microanatomy, which is essential for precise dissection through thoracoscopy, will be demonstrated.

As the left lateral position has been the preferred approach since introduction of thoracoscopy at our institute (4), all figures shown here were obtained from patients in the left lateral position (the upper and left sides correspond with the ventral and cranial aspects, respectively). In order to correspond with monitor images obtained from patients in the prone position, the figures need to be rotated 180 degrees to the right.

Indication for video-assisted thoracoscopic surgery (VATS)

Table 1 shows our indication for VATS. Principally, we do not indicate VATS for patients who received radiation, because mediastinal fibrosis caused by radiation makes microanatomy obscure.

Principle of thoracoscopic dissection and layer structures in the upper mediastinum

Figure 1 demonstrates the layer structure of the upper mediastinum. The outermost structure under the mediastinal pleura consists of the neural branches. The sympathetic branches from the right trunk dominate over the left and surround the oesophagus and thoracic duct. Black heavy arrows indicate our layer of dissection for total mobilization in the upper mediastinum. Almost all structures divided in the mediastinal mobilization run transversally, except the oesophagus, vagal nerves, and thoracic duct. Therefore, mobilization should be done transversally or orthogonally to the aorta and
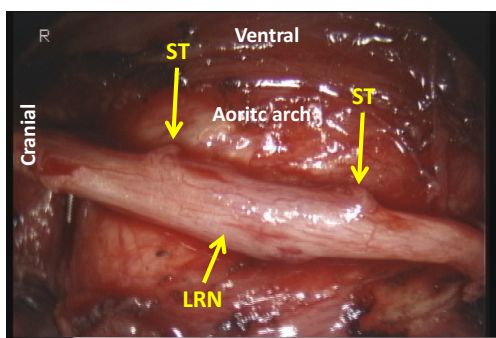
Figure 2 Epineurium of the left recurrent nerve. Under magnified view, the glossy appearance with the fine vessels running longitudinally is recognized. No vessel penetrates the epineurium in the dissection field. LRN, left recurrent nerve; ST, stump of the branch.
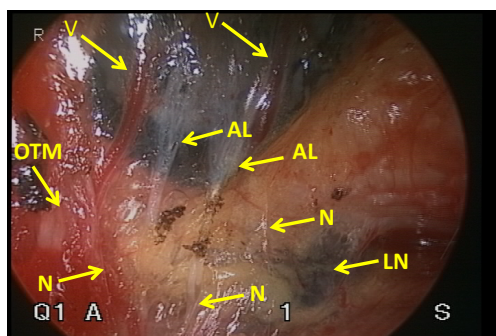

Figure 3 Magnified view of lymph nodes with anthracosis, its vessels and fine layer structure. V, fine vein of the lymph node; AL, afferent lymphatic vessel of the lymph node; OTM, oesophagotracheal muscle; LN, small lymph node with anthracosis; N, fine branch of nerve. Under magnified view, even the thickness of the wall of the vein and lymphatics can be compared, also two lymph nodes were separated with a layer consisting fine branches of nerve (n).

Figure 4 Illustration of the direction of the hilum of the lymph nodes in the upper mediastinum. Arrows indicate the direction of the hilum. Black, green and red arrows indicate the right and left recurrent nodes, and infracarinal nodes, respectively.

located on the convex capsule of the lymph node (*Figure 3*), while the artery and vasoactive unmyelinated nerve, and the vein and efferent lymphatic vessel are located at the hilum. These hilar structures serve to fix the node in place. In other words, each node has its own direction of hilar fixation. An understanding of the direction of the fixation facilitates nodal dissection (*Figure 4*).

Dissection of the right recurrent nodes

First, the mediastinal pleura are incised along the right vagal nerve, the right subclavian artery, and the ventral margin of the vertebra. Dividing the oesophagotracheal artery, arising from the right subclavian artery and running on the right side of the oesophagus to the anterior aspect of the trachea, at the anterior edge of the vertebra, the fatty tissue consisting of the recurrent nodes is mobilized. Then the epineurium of the vagal nerve is exposed and the right recurrent nerve is identified at its recurring point (just caudal to the right subclavian artery) (*Figure 5*). The dissection along the recurrent nerve is carried out by exposing the epineurium and dividing the oesophageal branches (commonly 4 or 5 esophageal branches are divided) to the caudal border of the right lobe of the thyroid gland. The nodes present dorsal to the recurrent nerve. The recurrent nerve should be carefully differentiated from the sympathetic nerve from the cervical ganglion (*Figure 6*). The sympathetic nerve runs along the

tracheobronchus. Identifying the structures under magnified view, the neural branches are divided without sealing to avoid the use of energy devices and unnecessary tissue damage. Under magnified view, the epineurium of the recurrent and vagal nerves can be identified easily as shiny fine membrane with fine vessels running longitudinally (*Figure 2*). As no vessel penetrates the epineurium in the dissection field, exposing the epineurium is the ideal layer of dissection. Under magnified view, the tiny lymph node structure is clearly visible. Histologically, only the afferent lymphatic vessels are
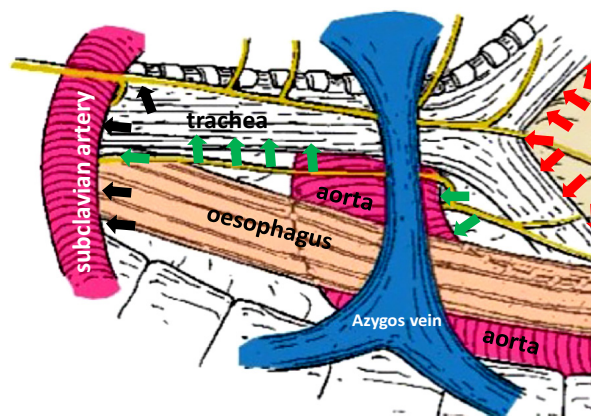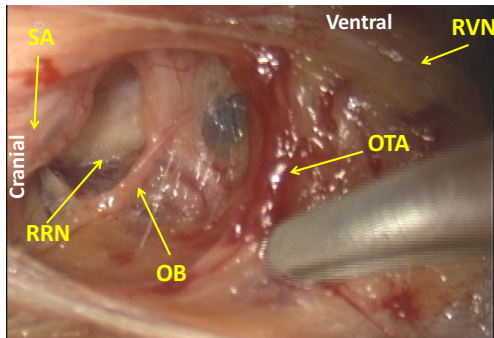
Figure 5 Dissection along the right recurrent nerve. Under magnified view, the epineurium of the recurrent nerve is clearly recognized. RVN, right vagal nerve; SA, subclavian artery; RRN, right recurrent nerve; OTA, oesophagotracheal artery; OB, oesophageal branch of the recurrent nerve;.
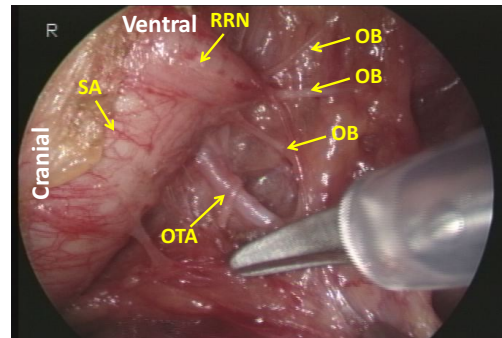

Figure 7 Anomalous branching of the oesophagotracheal artery. SA, subclavian artery; RRN, right recurrent nerve; OB, oesophageal branch of the recurrent nerve; OTA, oesophagotracheal artery (in this case, the artery branches off proximally very close to the recurrent nerve).
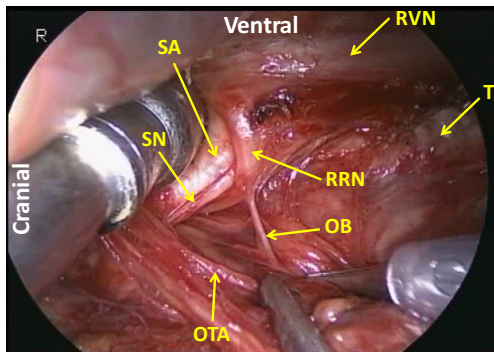

Figure 6 Differentiation of the right recurrent nerve from the sympathetic nerve. T, trachea; RVN, right vagal nerve; SA, subclavian artery; SN, sympathetic nerve from the cervical ganglion (The nerve runs on the subclavian artery, through the arch of the recurrent nerve, and to the frontal aspect of the trachea); RRN, right recurrent nerve; OB, oesophageal branch of the recurrent nerve; OTA, oesophagotracheal artery (this picture shows the common site of the artery).

Figure 8 Dissection along the right recurrent nerve up to the thyroid gland. SA, subclavian artery; RRN, right recurrent nerve; T, trachea; TA, inferior thyroidal artery; TG, thyroid gland; PT, parathyroid gland (in this case, the parathyroid gland is removed together with lymph nodes).

Mobilization of the dorsal aspect of the esophagus

Cranial to the aortic arch, the dorsal aspect of the oesophagus is rather avascular and anatomically simple. However, there can be three planes of dissection according to the right sympathetic branches (*Figure 9*). When the thoracic duct is preserved, dissection should be conducted along b1 in *Figure 1*. For total mediastinal mobilization, b2 in *Figure 1* is excised and the branches of the left sympathetic trunk are cut (*Figure 10*), then the left mediastinal pleura are exposed (*Figure 11*). The azygos arch is mobilized and divided following double ligation. The ligated ends are retracted through the chest wall ventrally and dorsally to enhance mediastinal exposure.

right subclavian artery, through the arch of the recurrent nerve, and to the frontal aspect of the trachea, and forms a V shape together with the vagal nerve, while in contrast the recurrent nerve forms a U shape. In some patients, the tracheoesophageal artery branches off proximal to the subclavian artery, near the recurrent nerve (*Figure 7*). In these patients, care should be taken not to injure the artery, so to avoid incurring palsy of the nerve. Depend on each patient's anatomy, the right inferior thyroidal artery can be recognized (*Figure 8*).
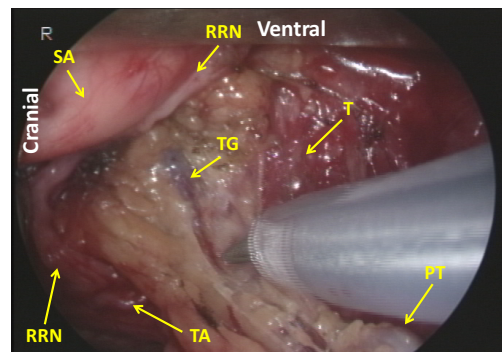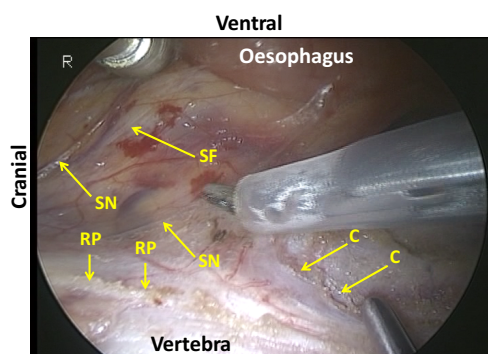
Figure 9 Mobilization of the dorsal aspect of the oesophagus (shallower layer). RP, cut edge of the right mediastinal pleura; SN, branch of sympathetic nerve (indicating b1 in *Figure 1*); C, cut edge of the layer consisting b1 in *Figure 1*; SF, Sibson's fascia (the thickened portion of endothoracic fascia between the first rib and the transverse process of the seventh cervical vertebra. The vessel runs parallel commonly).
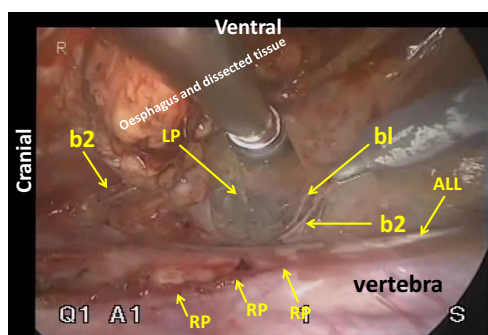

Figure 11 Exposure of the left mediastinal pleura and aortic arch. After dissection removing LST in Fig. 1, the left mediastinal pleura is properly exposed. O, oesophagus; A, aortic arch; LSA, left subclavian artery; LP, reflection of left mediastinal pleura on the aortic arch.

Figure 10 Mobilization of the dorsal aspect of the oesophagus (deeper layer). After dividing the leftmost branches of the right trunk, the left mediastinal pleura can be exposed properly. RP, cut edge of the right mediastinal pleura; ALL, anterior longitudinal ligament of the vertebra; b2, branches of the right trunk of the sympathetic nerve, encasing the thoracic duct (indicating b2 in *Figure 1*); bl, branches of the left trunk of the sympathetic nerve; LP, left mediastinal pleura.

Figure 12 Intercostobronchial artery (third intercostal artery) and thoracic duct. TD, thoracic duct (the thoracic duct runs most dorsally at the root of the intercostobronchial artery and is encased with the sympathetic nerve); O, oesophagus; ICBA, intercostobronchial artery; ICA, third intercostal artery; BA, right bronchial artery (the fine sympathetic nerve is seen running along the artery); SN, band of sympathetic nerve from the right thoracic trunk (in this case, the band is very thick).

The pleura is then incised along the anterior edge of the vertebral column dorsally and the right bronchial artery is doubly clipped and divided at its root as it bifurcates from the intercostobrachial artery (third intercostal artery) (*Figure 12*). Dissection is continued exposing the ventral aspect of the intercostobrachial artery as far as the right wall of the aortic arch. Then the right wall of the aortic arch is exposed. Cranial to the aortic arch, dissection
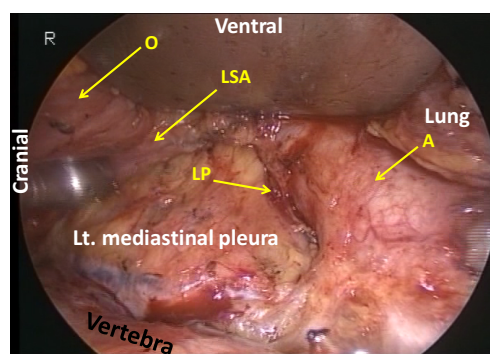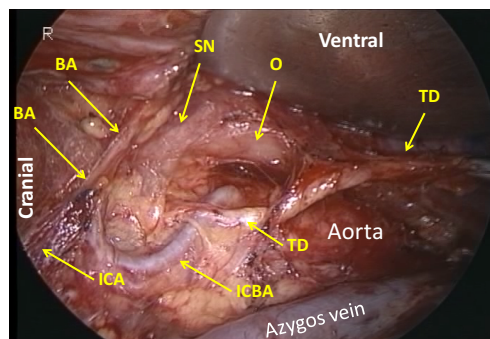
is carried out ventrally, exposing the left mediastinal pleura, until pulsation of the left subclavian artery is recognized. Because the thoracic duct is covered with this fibrous membrane, the fibrous membrane should be divided for combined resection of the duct (*Figure 13*). The stump of thoracic duct shows particular appearance because of its intramural smooth muscle (*Figure 14*). At the level of the pulmonary hilum, the lymphatic collecting ducts from the chest wall and the mediastinum, draining into
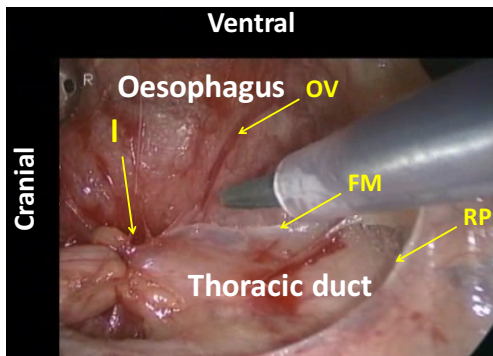
Figure 13 Thoracic duct. RP, cut edge of the right mediastinal pleura; FM, fibrous membrane (encases the thoracic duct together with the aorta); L, ligation on the thoracic duct; OV, fine vessel on the oesophagus.
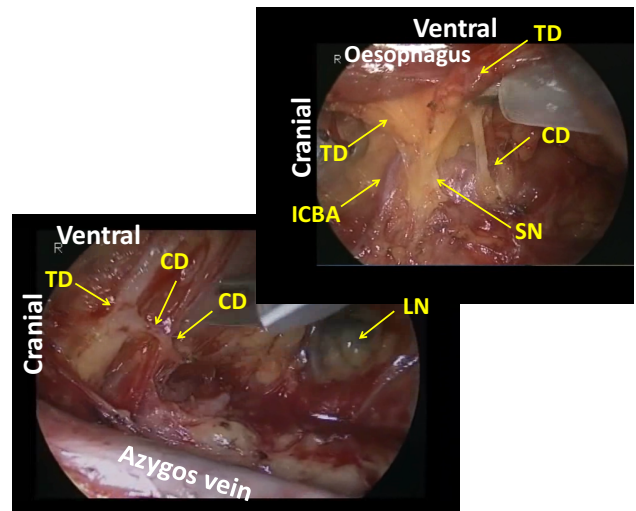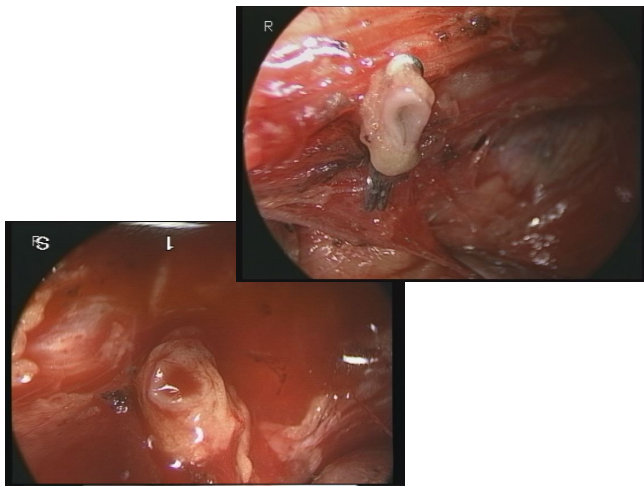

Figure 14 Stump of the thoracic duct. The upper right picture shows proximal stump of the thoracic duct at the level of crossing-over the left subclavian artery. The lower left picture shows distal stump of the thoracic duct at the level of the pulmonary hilum. Both pictures demonstrate the particular appearance of the stump of the thoracic duct because of its intramural smooth muscle.

Figure 15 Lymphatic collecting duct. The upper right picture shows the collecting duct from the thoracic wall and the lower left picture shows the collecting duct from the mediastinum. The collecting duct appears thicker than the afferent lymphatic vessel (*Figure 3*) because of its intramural smooth muscle. TD, thoracic duct; CD, collecting duct; ICBA, intercostobronchial artery; SN, branches of the right trunk of the sympathetic nerve; LN, lymph node.
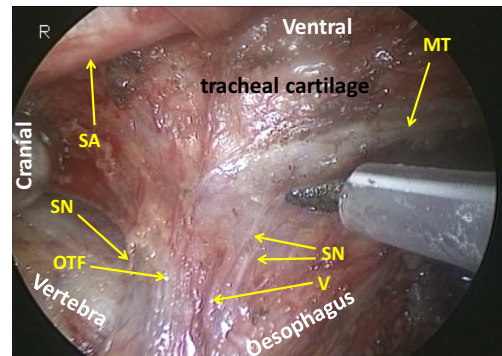

Figure 16 Dividing the oesophagotracheal fibrous band (right side). SA, right subclavian artery; MT, membranous part of the trachea; OTF, oesophagotracheal fibrous band; SN, fine branch of sympathetic nerve in the oesophagotracheal fibrous band; V, vessels in the oesophagotracheal fibrous band.

the thoracic duct, are observed (*Figure 15*).

Mobilization of the ventral aspect of the esophagus

The right vagal nerve is divided at the level of the tracheal bifurcation, just caudal to the pulmonary branches. The oesophagus is mobilized from the trachea by dividing the neural and vascular communication between the bilateral edges of the tracheal cartilage and the oesophagus (*Figure 16*). There is no vascular communication between the membranous part of the trachea and the oesophagus. At the level of the tracheal bifurcation, the oesophagus makes contact with the membranous part of the left main bronchus and is kept in place by the left vagal nerve and branches of the bronchial artery coming from the left side
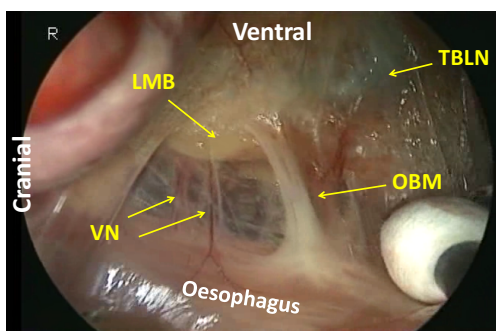
Figure 17 Muscular fixation of the oesophagus. LMB, left main bronchus; TBLN, tracheobronchial lymph node; OBM, oesophagobronchial muscle; VN, fine vessels and nerves between the oesophagus and bronchus. The muscle was confirmed to consist of the smooth muscle histologically.
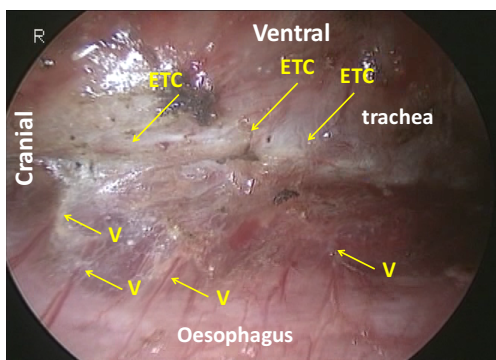

Figure 18 Dividing the oesophagotracheal fibrous band (left side). ETC, left edge of the tracheal cartilage; V, fine vessels in the oesophagotracheal fibrous band.
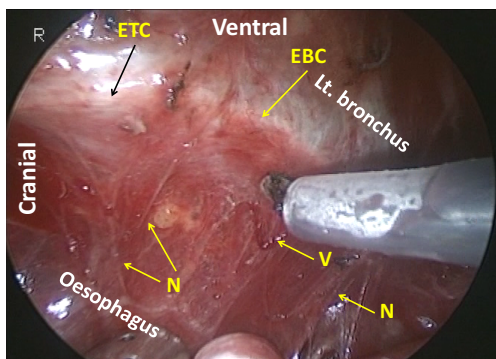

Figure 19 Mobilization of the oesophagus from the left side of the trachea. ETC, left edge of the tracheal cartilage; EBC, left edge of the bronchial cartilage; N, fine nerves in the oesophagotracheal fibrous band; V, fine vessels in the oesophagotracheal fibrous band.

of the oesophagus. Under magnified view, the oesophagus is found to be fixed in place by the muscular structure. A bundle of the longitudinal muscle of the oesophagus separates from the wall, runs cranially and enters on the left edge of the cartilage part of the tracheobronchus (the oesophagotracheal muscle) (*Figure 17*).

Dissection of the left recurrent nodes

Following mobilization of the dorsal and left aspects of the oesophagus, the tracheobronchus is retracted ventrally to separate it from the now dorsally retracted oesophagus. The right oesophagotracheal fibrous band is excised and the trachea is gradually retracted ventrally and rotated to the left applying a retractor on the right edge of the tracheal cartilage in order to expose the left side. Then the left oesophagotracheal fibrous band is excised (*Figure 18*), and with the aid of an angulated camera and progressive dorsal retraction of the oesophagus, the dissection is continued on the left side of the cartilage part of the trachea where the fine pretracheal branches of the left recurrent laryngeal nerve are cut (*Figure 19*). As a result, the sympathetic cardiac branches from the cervical ganglion can be recognized under the fine membrane (*Figures 1,20*). Because there are no vessels penetrating this fine membrane, mobilization of the tissue from this membrane can be performed bluntly without any bleeding. Following this mobilization, the left recurrent laryngeal nerve together with its surrounding lymph nodes can be retracted dorsally by retracting the oesophagus and applying traction on the oesophageal branches of the nerve (*Figures 21,22*). This improves the exposure which facilitates further cranial dissection. Superiorly in the neck, several fine branches arising from the left recurrent laryngeal nerve give this area a characteristic appearance like a rake signifying the upper limit of the thoracic dissection. Finally, the left recurrent nerve is separated from the tissue including the lymph nodes and the oesophagus by dividing 5 to 10 of its oesophageal branches. For safe and complete isolation of the nerve, its epineurium (*Figures 2,23*), which appears glossy with fine vessels running longitudinally, should be exposed. After total isolation of the left recurrent laryngeal nerve, the left side of the lymphatic tissue is separated by exposing the left subclavian artery and dividing the thoracic duct as it approaches the left subclavian artery. Cranial border of dissection along the left recurrent nerve
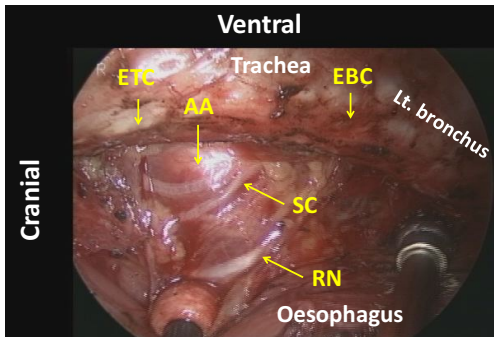
Figure 20 Exposure of cardiac branch of sympathetic nerve from the cervical ganglion. ETC, edge of the tracheal cartilage; EBC, edge of the bronchial cartilage; AA, right wall of the aortic arch; RN, left recurrent verve; SC, sympathetic cardiac nerve from the cervical ganglion (this nerve presents in front of the recurrent nerve and is covered with the fine fibrous membrane. There are no vessels penetrating this membrane).
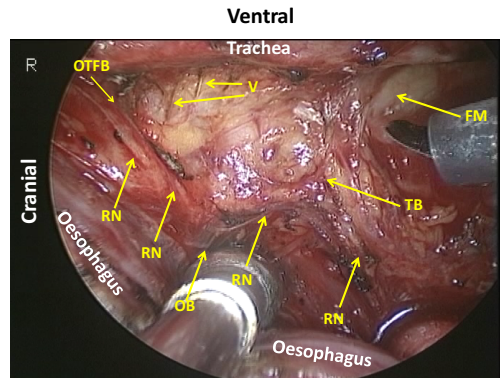

Figure 22 Dissection along the left recurrent nerve. RN, left recurrent verve; FM, fine fibrous membrane covering the sympathetic cardiac nerve (there is no vessel penetrating this membrane); V, vessel of a lymph node; OTFB, cut edge of the oesophagotracheal fibrous band; OB, oesophageal branch of the left recurrent nerve (bending of the recurrent nerve to the oesophagus indicates there is a oesophageal branch); TB, tracheal branch of the left recurrent nerve (bending of the recurrent nerve to the trachea indicates there is a tracheal branch).
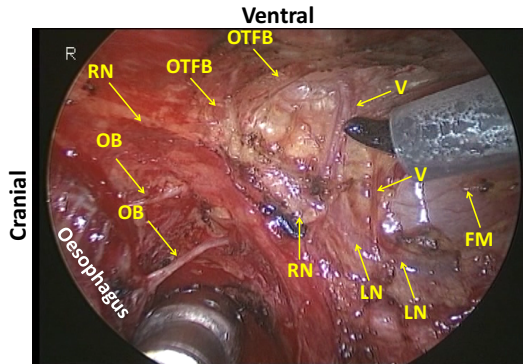

Figure 21 Dissection along the left recurrent nerve. RN, left recurrent verve; FM, fine fibrous membrane covering the sympathetic cardiac nerve (there is no vessel penetrating this membrane); V, vessel of a lymph node (commonly seen in front of the nodes. cf. *Figure 1*, vn); LN, lymph node; OTFB, cut edge of the oesophagotracheal fibrous band; OB, oesophageal branch of the left recurrent nerve.
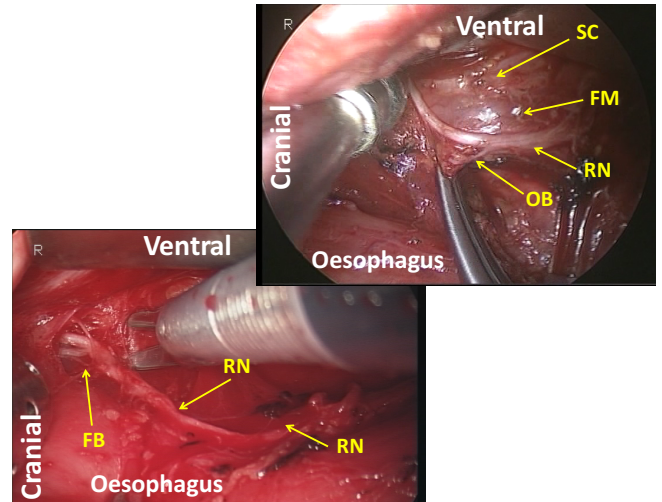

Figure 23 Isolation of the left recurrent nerve. SC, sympathetic cardiac nerve from the cervical ganglion; FM, fine fibrous membrane covering the sympathetic cardiac nerve; RN, left recurrent nerve; OB, oesophageal branch of the recurrent nerve; FB, fine oesophageal and tracheal branches of the recurrent nerve (a rake appearance signifies the upper limit of the thoracic dissection).
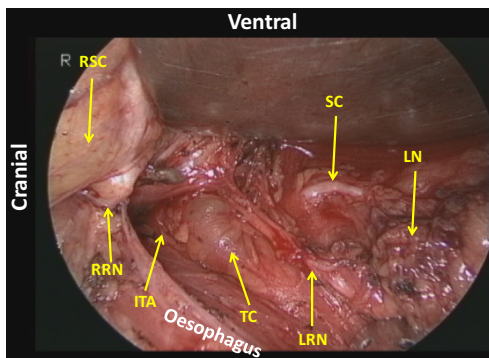
Figure 24 Cranial border of dissection along the left recurrent nerve. RSC, right subclavian artery; RRN, right recurrent nerve; ITA, left inferior thyroidal artery; TC, cystic lesion in the left lobe of the thyroid (in this case cystic lesion in the left lobe of the thyroid was detected before surgery); LRN, left recurrent nerve; LN, lymph nodes along the left recurrent nerve; SC, sympathetic cardiac nerve from the cervical ganglion.
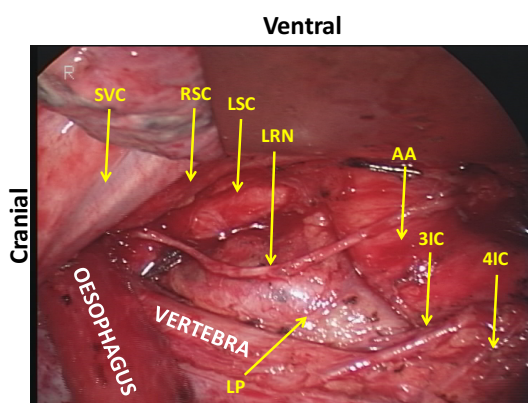

Figure 25 After supracarinal dissection. SVC, superior vena cava; RSC, right subclavian artery; LSC, left subclavian artery; LRN, left recurrent nerve; AA, aortic arch; LP, left mediastinal pleura; 3IC, third intercostal artery; 4IC, 4th intercostal artery.
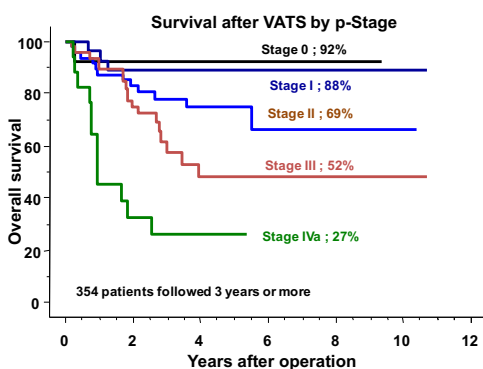

Figure 26 Survival after thoracoscopic oesophagectomy by p-Stage in patients followed for 3 years or more.

from the chest is at the caudal pole of the thyroid gland, similar as on the right side (*Figure 24*). Overall, anatomical boundaries for the dissection of the left recurrent laryngeal lymph nodes include the left side of the cartilage part of the trachea, cardiac branches of the sympathetic nerve, the left subclavian artery and the left mediastinal pleura where en-bloc resection without direct traction on the recurrent laryngeal nerve is the main surgical principle (*Figure 25*).

Efficacy of MIE

Recent population-based analyses revealed that slightly more than 30% of cases of oesophagectomy for cancer are performed thoracoscopically and the percentage is increasing (5-7). However, there is insufficient high-level evidence justifying the thoracoscopic approach. Only one prospective randomized controlled trial (8) and five meta-analyses (9-13) evaluating the benefits of thoracoscopy over open surgery have been reported. A British study demonstrated that there was no significant difference in outcomes between the minimally invasive group and the open surgery group, except for the former having a significantly higher risk of reintervention with increasing odds ratio with every progressive study year (5). Another study from Japan revealed that, compared with open surgery, minimally invasive oesophagectomy was associated with a higher incidence of overall morbidities (40.8% *vs.* 44.3%), anastomotic leakage (12.5% *vs.* 14.9%), and reintervention (5.6% *vs.* 8.0%) (6). Thoracoscopic oesophagectomies done by surgeons in the learning phase which are inevitably included in population-based analyses might be the cause of variance with the other studies. The operative and in-hospital mortality after oesophagectomy is conversely related with hospital volume (14) and the same result is seen after thoracoscopic oesophagectomy. The outcome of oesophagectomy strongly depends on the surgeon's experience. When it is performed thoracoscopically, additional experience and skill are required of surgeons (15).

No oncologic adverse effects were detected in meta-analyses (9-13). The thoracoscopic approach did not negatively affect the quality of mediastinal dissection, retrieval of mediastinal nodes, or survival. In our experience, survival after thoracoscopic oesophagectomy was 92%, 88%, 69%, 52% and 27% at 5 years for pStage 0, 1, 2, 3, and 4, respectively (*Figure 26*). The indication was the same as that for open surgery and perioperative treatment consisted of neoadjuvant and/or adjuvant chemotherapy. Although the data are retrospective, survival was favorable compared

with that after open oesophagectomy and similar to that for gastric cancer. However, the evidence of oncologic superiority of thoracoscopy over open surgery is still being evaluated with pragmatic randomized controlled trials.

The quality of dissection has improved with increased understanding of the mediastinal anatomy *in vivo* under magnified view. The novel anatomical knowledge enhanced through thoracoscopy can serve as feedback for open surgery to improve the quality of mediastinal dissection. In this chapter, the microanatomy usually recognized in the treatment of non radiated patients is presented. It is supposed that in patients undergoing neoadjuvant treatment, especially radiation, the fine anatomy may become obscure because of mediastinal fibrosis. Even so, understanding of the innate microanatomy is essential to ultimately perform the ideal oesophagectomy, even in patients after neoadjuvant therapy.

Acknowledgements

Footnote

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