A Standardized Protocol for Robot-Assisted Minimally Invasive Esophagectomy: Improving Efficiency and Reducing Costs

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Standardization

Mediastinal Dissection

Cost-Effectiveness

Surgical Technique

Abstract:

Background: Robot-assisted minimally invasive esophagectomy (RAMIE) has shown potential benefits over conventional procedures for esophageal cancer. However, uniform surgical protocols are lacking, leading to variability in outcomes and increased costs.

Methods: This retrospective study included 180 patients with esophageal cancer who underwent RAMIE between May 2018 and September 2024. A standardized approach, termed counterclockwise partitioned mediastinal dissection (CPMD), was introduced in 114 of these cases. Perioperative parameters, including operative time, blood loss, complications, and cost of disposable instruments, were compared between patients treated before and after protocol standardization.

Results: Among the 114 patients who received the standardized RAMIE protocol, the median thoracic console time significantly decreased to 148 minutes, with overall blood loss reduced to 62 ml. No conversions to open surgery were required in either cohort. Compared to the pre-standardization group, postoperative complications—including recurrent laryngeal nerve paralysis—were lower, and only one patient needed reoperation. Importantly, reusing robotic instruments from the thoracic phase in the abdominal phase reduced disposable instrument costs, resulting in a savings of approximately 168,000 Japanese Yen (USD 1,050) per case.

Conclusion: Implementing a standardized RAMIE protocol enhances procedural efficiency, reduces blood loss, and lowers costs without compromising surgical or oncological outcomes. This approach may facilitate broader adoption of RAMIE as a safe and cost-effective strategy for esophageal cancer surgery.

Introduction

Robot-assisted minimally invasive esophagectomy (RAMIE) has emerged as a promising alternative to conventional open or thoracoscopic approaches, demonstrating reduced complications and improved survival outcomes [1-5]. Its adoption is increasingly gaining traction in multiple healthcare institutions, largely due to the surgical robot's advanced features, including intuitive instrument control, tremor filtration, and enhanced visualization [3, 6-8]. These attributes are particularly advantageous for the complex anatomical dissection and precise manipulation required in esophageal cancer surgery.

Despite these advances, significant gaps remain. Current literature and clinical practice lack consensus on key procedural details, such as standardized patient positioning, port placement, and surgical techniques [9, 10]. This variability has hindered the establishment of uniform treatment protocols, leading to substantial variations in outcomes [9]. Moreover, prolonged operative times, heightened costs, and the risk of catastrophic complications—especially during the learning curve, where injuries to major blood vessels, airways, or nerves can have dire consequences—continue to pose significant challenges [11, 12]. To ensure both safety and efficiency in robotic esophageal surgery, it is imperative to develop standardized protocols tailored to the unique capabilities of robotic systems.

Since the introduction of RAMIE at our institution in 2018, following its approval for coverage under Japan's national insurance system, we initially adapted thoracoscopic esophagectomy techniques by performing abdominal procedures laparoscopically and conducting cervical procedures simultaneously. Although we observed enhanced maneuverability in thoracic operations due to the robotic platform, short-term outcomes did not substantially improve compared to standard thoracoscopic approaches, and prolonged operative times along with increased costs emerged as significant challenges. To overcome these limitations, we systematically refined our surgical methods, ultimately achieving a standardized approach to RAMIE. By doing so, we sought to, streamline the learning curve, and reduce operative times and expenses, thereby improving patient outcomes. In this paper, we describe the standardized RAMIE technique we have developed, elucidate the core concepts driving its application, and present data demonstrating its effectiveness, with the overarching goal of establishing a replicable, optimized protocol for robotic esophageal surgery.

Materials and Methods

Ethical consideration

This retrospective study was approved by the Institutional Review Board of our institution (Approval no:2024-17) and was conducted in accordance with the principles of the Declaration of Helsinki.

Patients

This study included all the cases of robot-assisted minimally invasive esophagectomy (RAMIE) performed at Keiyukai Sapporo Hospital between May 2018 and September 2024. All the procedures performed were Mckeown esophagectomies with three field lymph node dissections. Outcomes were compared between two cohorts: 114 cases performed after implementing a standardized surgical protocol and 66 cases completed prior to its establishment. All procedures utilized the da Vinci Xi Surgical System (Intuitive Surgical, Sunnyvale, CA, USA) and were conducted by a single experienced robotic surgeon using the standardized protocol. Specimens were evaluated based on the 12th Edition of the Japanese Classification of Esophageal Cancer by the Japan Esophageal Society. Patient data, including demographic characteristics, perioperative outcomes and cost of the perishable goods used in the surgery, were collected retrospectively.

Operative Procedure

1. Thoracic Procedure in RAMIE

A. Set Up

Patients were placed prone on a flexed operating table, with the lower body tilted approximately 5° downward. The left arm was positioned alongside the torso, while the right arm was elevated and internally rotated. The patient's head was rotated to the right and secured. Although double-lung ventilation was standard, single-lung ventilation could be employed based on individual patient's medical history or comorbidities.

The ports are placed as follows:

- 3rd intercostal space at the mid-axillary line
- 5th intercostal space at the posterior axillary line
- 7th intercostal space at the posterior axillary line
- 9th intercostal space at the scapular line

Ports were placed at the 3rd, 5th, 7th, and 9th intercostal spaces (mid-axillary, posterior axillary, and scapular lines), and an assistant 12-mm port was introduced at the 6th intercostal space along the mid-axillary line (Figure 1). All ports were inserted vertically with a minimum of a four-finger breadth separation, and pneumothorax pressure was maintained at 8 mmHg. The patient cart approached from the right side of the operating table.

The following instruments are attached to the respective arms:

- **Arm 1**: Long Bipolar Grasper® (LongB)
- **Arm 3**: Maryland Bipolar Forceps® (Maryland)
- **Arm 4**: Cadiere Forceps® (Cadiere)

LongB and Maryland were coupled with an ERBE VIO dV® system in soft coagulation mode (Effect7) for double-bipolar technique. Additional instruments, such as Monopolar Curved Scissors®, Vessel Sealer Extend® (VS), and a Clip Applier®, could be interchanged on Arm 3 as needed.

B. Thoracic Surgical Technique

The thoracic phase followed a standardized approach termed **Counterclockwise Partitioned Mediastinal Dissection (CPMD)** (Figure 2). Key principles of this technique were:

1. Dissecting and resecting in a counterclockwise sequence, starting from the anterior middle and lower mediastinum, then moving to the anterior upper mediastinum, posterior upper mediastinum, and finally the posterior middle and lower mediastinum.

2. Employing a double-bipolar technique with soft coagulation mode to integrate dissection, cutting, and hemostasis using a single instrument.
3. Developing each surgical field without an additional assisting operator.

Key Steps of CPMD:

1) Anterior Middle and Lower Mediastinum Dissection

The inferior pulmonary ligament was divided, and tissue behind the pericardium dissected to the left mediastinal pleura, creating a sheet-like structure containing lymph nodes No. 110 and No. 111 (Figure 3a). Progressing cranially, the inferior pulmonary vein was exposed, and lymph nodes No. 107 and No. 109 were separated from the pericardium. The azygos vein arch and right bronchial artery were divided, with the right vagus nerve's pulmonary branches preserved and its esophageal branches divided (Figure 3b).

2) Anterior Upper Mediastinum (Right Recurrent Laryngeal Nerve Dissection)

The right vagus nerve trunk is carefully followed in a cranial direction, while the esophagus is gently mobilized away from the membranous tracheal wall. As the vascular sheath of the right subclavian artery is opened and the underlying tracheal cartilage is exposed, the right recurrent laryngeal nerve and its esophageal branches become clearly visible, collectively forming a sheet-like structure that encompasses the No. 106recR lymph nodes. To facilitate a precise and safe dissection, the dorsal tissues surrounding the right recurrent laryngeal nerve are excised using monopolar curved scissors, without use of energy (Figure 3c). The upper boundary of the No. 106recR lymph node dissection is defined by the palpable pulsation of the inferior thyroid artery, serving as a reliable anatomical landmark.

3) Posterior Upper Mediastinum (Left Recurrent Laryngeal Nerve Dissection)

The mediastinal pleura is incised dorsally to the esophagus, exposing a loose connective tissue layer. Within this field, the thoracic duct lies outside the primary dissection plane and is preserved unless it is directly infiltrated by the tumor. As the dissection advances toward the lower mediastinum, the proper esophageal artery is clipped and divided to facilitate adequate exposure.

With the esophagus gently elevated dorsally, the contiguous tissue on its left side is carefully separated from the left tracheal wall cartilage to visualize the left recurrent laryngeal nerve. Lymph nodes in this area are bluntly dissected away from the nerve, while small vessels are coagulated and divided to maintain a clear operative field. The combined tissue block containing the left recurrent laryngeal nerve and its associated lymph nodes is then meticulously detached from the esophagus. Using a stapler introduced through the assistant port, the esophagus is generally transected at the level of the aortic arch. The transection level is determined by the tumor's location to ensure that the resection margin is free of tumor. Finally, the proximal esophageal stump is retracted ventrally to adequately expose the No. 106recL lymph node–bearing tissue, which is then sharply excised from the left recurrent laryngeal nerve using monopolar curved scissors without the use of energy (Figure 3d).

4) Posterior Middle and Lower Mediastinum Dissection

With the distal esophageal stump retracted ventrally, the previously dissected anterior and posterior tissues are gathered and mobilized as a cohesive sheet along the left side of the esophagus. The esophageal branches of the left vagus nerve are divided at the lower border of the left main bronchus. In the absence of tumor invasion, the left mediastinal pleura is preserved. This tissue sheet is then gently advanced downward toward the diaphragm, ultimately revealing the entire circumference of the diaphragmatic crura (Figure 3e).

2. Abdominal Procedure in RAMIE

A. Set Up

The patient is placed in a supine position with a shoulder pillow beneath the shoulders to achieve neck extension. Both arms remain secured at the patient’s sides, and the operating table is adjusted to a head-up tilt of approximately 11–13° to optimize surgical exposure. An 8-mm port is introduced subumbilically to establish a pneumoperitoneum at 8 mmHg. Two additional 8-mm ports are placed on the right side of the abdomen, one on the left side, and a 12-mm assistant port is inserted on the far-left side. The instrument setup mirrors that used in the thoracic phase: the right abdominal port is connected to Arm 2 for endoscopic visualization, while Arms 1, 3, and 4 are equipped with the Long Bipolar Grasper (LongB), Maryland, and Cadiere instruments, respectively. A Nathanson liver retractor is then employed to elevate the lateral segment of the liver, ensuring adequate operative space (Figure 4a).

B. Surgical Technique

The abdominal procedure employs the following modifications:

1. Utilizing the same instruments as the thoracic procedure.
2. Placing the assistant port laterally on the left side.
3. Employing the scope through the right lateral port for lesser curvature dissection and subsequently repositioning it to the subumbilical port for greater curvature dissection.

1) Lesser Curvature Dissection

The right gastric artery is first identified and preserved, ensuring blood supply to the stomach is maintained. After incising the lesser omentum, the left gastric artery is mobilized, providing clear exposure of the splenic and common hepatic arteries. Lymph node dissection in the No. 8a station is then carried out in a lateral direction, followed by clipping and division of the left gastric vessels. With the posterior aspect of the gastric lesser curvature elevated, meticulous lymphadenectomy is performed along the course of the splenic artery and the branches of the inferior phrenic artery. The short gastric vessels are either clipped or divided using the VS, extending cranially toward the upper pole of the spleen to complete the nodal dissection in this region (Figure 5a).

2) Greater Curvature Dissection

With the endoscope repositioned to Arm 3, the Cadiere forceps in Arm 1, the Long Bipolar Grasper

(LongB) in Arm 2, and the Maryland bipolar forceps in Arm 4 (Figure 4b), the stomach is gently retracted cranially using the Cadiere. The greater omentum is incised to access the lesser sac, allowing for dissection of the right gastroepiploic vessels down to their root. Moving toward the left side of the patient, the left gastroepiploic vessels are identified and divided at their origin. With these vessels addressed, the upper portion of the stomach is shifted to the patient's right. Meanwhile, the assistant retracts the transverse mesocolon caudally near the inferior pole of the spleen (Figure 5b).

The short gastric vessels are then managed in a caudal direction and connected to the previously dissected lesser curvature margin. Lastly, the esophagus is freed from the hiatus. After ensuring complete mobilization, the hiatus is closed with non-absorbable sutures, securing the operative field and maintaining anatomical integrity.

Gastric Conduit Preparation and Reconstruction

A 5–8 cm upper midline laparotomy was performed to create a 3-cm diameter gastric conduit extracorporeally. Since the introduction of RAMIE, the retrosternal route has been our first choice for conduit elevation due to ease of managing anastomotic leaks or conduit-related complications when they occur. The posterior mediastinal route is chosen when the retrosternal route is not viable because of previous surgeries or cardiac conditions. The cervical procedure is performed concurrently with the preparation of the gastric conduit. Following cervical lymphadenectomy, the proximal esophageal stump is pulled out through the cervical incision, and the final transection line of the esophagus is determined based on the tumor location and the length of the cervical esophageal stump. In all cases, a hand-sewn end-to-end anastomosis was performed in the neck between the esophagus and the gastric conduit. For the posterior mediastinal route, the robot is re-docked, and the gastric conduit is fixed to the hiatus using a few non-absorbable sutures.

Statistical analysis

Comparisons between pre- and post-standardization groups were conducted using the Mann-Whitney U test for the continuous data and Fischer-extact test and χ^2 test for the categorical data, with a significance level set at $p < 0.05$. All the statistical analysis were performed using SPSS version 26.0 (IBM Corp., Armonk, New York, USA).

Result

A total of 180 patients underwent RAMIE during the observation period, 114 of whom were operated on after the implementation of the standardized surgical protocol. There were no significant differences in gender distribution or median age between the pre-standardization (n=66) and post-standardization (n=114) groups. Tumor location was also comparable; however, a significantly greater proportion of patients in the post-standardization cohort presented with c-stage II or higher disease. Additionally, the use of neoadjuvant therapy increased significantly following standardization, with 35 patients receiving chemotherapy and 4 undergoing chemoradiotherapy (Table 1).

In terms of surgical parameters, the median total operative time was reduced to 464 minutes in the post-standardization group, although this difference was not statistically significant (Table 2). By contrast, the thoracic console time showed a significant decrease to 148 minutes, and median blood loss was significantly lowered to 62 ml (Table 2). Importantly, through reducing the use of disposable laparoscopic instruments in the abdominal portion and reusing robotic instruments from the thoracic phase, we achieved a cost reduction of approximately 168,000 JPY (USD 1,050 at 1 USD=160 JPY) per case. No patients in either group required conversion to open thoracotomy or laparotomy.

Postoperative outcomes also improved with the standardized approach. The incidence of recurrent laryngeal nerve paralysis declined to 4.4%. While anastomotic leakage occurred in some patients, only one case required reoperation due to gastric conduit necrosis; all other leakage cases were managed conservatively. There were no surgery-related mortalities in either group (Table 2).

Discussion

In this study, we demonstrated that implementing a standardized surgical protocol in RAMIE, which utilized double bipolar system using soft coagulation mode significantly improved procedural efficiency, reduced blood loss, and decreased operative costs. By employing the CPMD approach, we shortened thoracic console time, minimized the need for instrument exchanges, and maintained oncological rigor. Together, these findings underscore our approach as a reproducible, cost-effective standard for RAMIE.

Central to these improvements is the standardization of the surgical technique and workflow. A robotic approach offers significant advantages over thoracoscopic surgery, primarily due to enhanced visualization and increased precision in the upper mediastinum—facilitating more thorough lymph node dissection and potentially reducing overall complications [13-15]. Nonetheless, prolonged operative times and a steep learning curve remain notable challenges of RAMIE, and although robotic systems excel at precise, focused dissections, they can be less efficient in wider surgical fields, often necessitating additional time for repositioning [15, 16].

To overcome these drawbacks while capitalizing on the strengths of robotic technology, various teams have reported standardized workflows [14, 16]. In our series, reorganizing the thoracic procedure—adopting a counterclockwise dissection pattern, employing a double-bipolar technique using soft coagulation mode, and introducing a partition-like dissection line—streamlined operative steps and minimized frequent field repositioning. These modifications preserved oncological rigor, as meticulous visualization and careful handling of critical structures (e.g., the recurrent laryngeal nerves) allowed for comprehensive lymph node dissection and likely contributed to a lower incidence of nerve palsy. Other studies have also shown similar results [15]. This approach significantly shortened thoracic operative times while maintaining a low complication rate, aligning with similar findings reported in the literature. Ultimately, understanding the inherent limitations and advantages of the robotic platform and tailoring a standardized strategy to each institution's workflow are essential to reducing operative times without compromising surgical quality or patient safety.

Although the benefits of a robotic approach for the thoracic portion of RAMIE are well established—largely due to its technical advantages and favorable postoperative outcomes—the optimal technique for the abdominal phase remains less defined [9]. Many centers favor a laparoscopic approach, while others report success with hand-assisted laparoscopy or even laparotomy [9, 17]. Our group initially employed a hybrid strategy, performing the thoracic portion robotically and the abdominal portion laparoscopically, allowing for concurrent cervical dissection in McKeown esophagectomy [9]. However, a recent international collaborative study comparing this hybrid model with full RAMIE showed no significant difference in operative time, although the study included only Ivor Lewis esophagectomies without a cervical phase [18]. Consistent with these findings, our own data revealed that the hybrid approach did not confer substantial short-term advantages and, in fact, was associated with prolonged operative times. Consequently, we transitioned to a fully robotic approach, completing the robotic abdominal portion before initiating the cervical phase. Despite this change, total operative time did not significantly increase. Notably, Sato et al, [19] have proposed a new abdominal docking method that enables simultaneous robotic abdominal manipulation and cervical dissection, potentially further reducing total operative time.

From an economic perspective, our standardized full-RAMIE protocol allowed us to make more judicious use of resources. Employing the same instruments and energy devices in both the thoracic and abdominal phases significantly reduced expenses associated with disposable laparoscopic equipment that were needed while performing the abdominal portion laparoscopically such as trocars and energy devices such as laparoscopic ultrasonic shears. In addition, repositioning the assistant port and scope improved visualization and decreased operative complexity, thereby mitigating the risk of instrument interference. These refinements translated into cost savings of approximately 168,000 JPY (about USD 1,050 at 1 USD = 160 JPY), underscoring the cost-effectiveness of a fully robotic technique. Notably, our experience suggests that even in McKeown esophagectomy, it is possible to lower costs and reduce operative time while maintaining low complication rates by adopting a full-RAMIE approach.

Despite the promising findings, our study has several limitations. First, it was a retrospective, single-institution analysis, performed by a single experience surgeon, which may limit the generalizability of the results. Additionally, the absence of a randomized control group makes it challenging to definitively attribute observed improvements solely to the standardized technique. Finally, while we demonstrated short-term benefits, longer-term outcomes and the potential impact on survival and quality of life warrant further investigation.

Further prospective and multicenter investigations with surgeons with various experience are warranted to validate our results and determine their applicability to diverse clinical settings. Future directions include the prospective evaluation of standardized RAMIE protocols across multiple institutions to enhance external validity. Investigations into long-term outcomes, including survival and postoperative quality of life, would provide valuable insight into the lasting benefits of our approach. Additionally, incorporating technological advancements, refining visualization tools, and exploring adjunctive training methods could further optimize procedural execution and outcomes.

Conclusion

In conclusion, our findings indicate that a standardized RAMIE protocol can significantly streamline operative workflows, reduce intraoperative blood loss, and lower procedural costs without compromising oncological or postoperative outcomes. This approach may facilitate broader adoption of RAMIE as a safe and cost-effective strategy for esophageal cancer surgery.

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Table 1: Clinicopathologic Patient Characteristics

	Pre-standardization (n=66)	Post-standardization (n=114)	P value
Age	66 (41-90)	71 (42-84)	
Sex (Male/Female)	47/19	76/38	0.52
Tumor location (Te/Jz)	60/6	92/22	0.07
Stage (0/I/II/III/IV)	5/34/21/5/1	2/38/37/33/4	<0.01*
Preoperative			<0.01*
Chemotherapy	2	35	
Chemoradiotherapy	1	4	

Continuous data is presented as Median (range), categorical data is presented as number of patients.
*denotes statistical significance

Table 2: Operative Outcome

	Pre-standardization (n=66)	Post-standardization (n=114)	P value
Operation time (minutes)	476 (383-604)	464 (324-585)	0.32
Console/laparoscopic time (minutes)			
Thoracic procedure	185 (141-300)	148 (89-244)	<0.01*
Abdominal procedure	92.5 (55-162)	88 (52-145)	0.17
Total bleeding (ml)	120 (10-510)	62 (10-400)	<0.01*
Post-operative complications	31 (47.0%)	28 (24.6%)	<0.01*
Recurrent nerve palsy	13 (19.7%)	5 (4.4%)	<0.01*
Anastomotic leakage	7 (10.6%)	14 (12.3%)	0.74
Chylothorax	1 (1.5%)	1 (0.9%)	0.69
Surgical site infection	10 (15.2%)	8 (7.0%)	0.08

Continuous data is presented as Median (range), categorical data is presented as number of patients (percentage).

*denotes statistical significance

Figure Legend

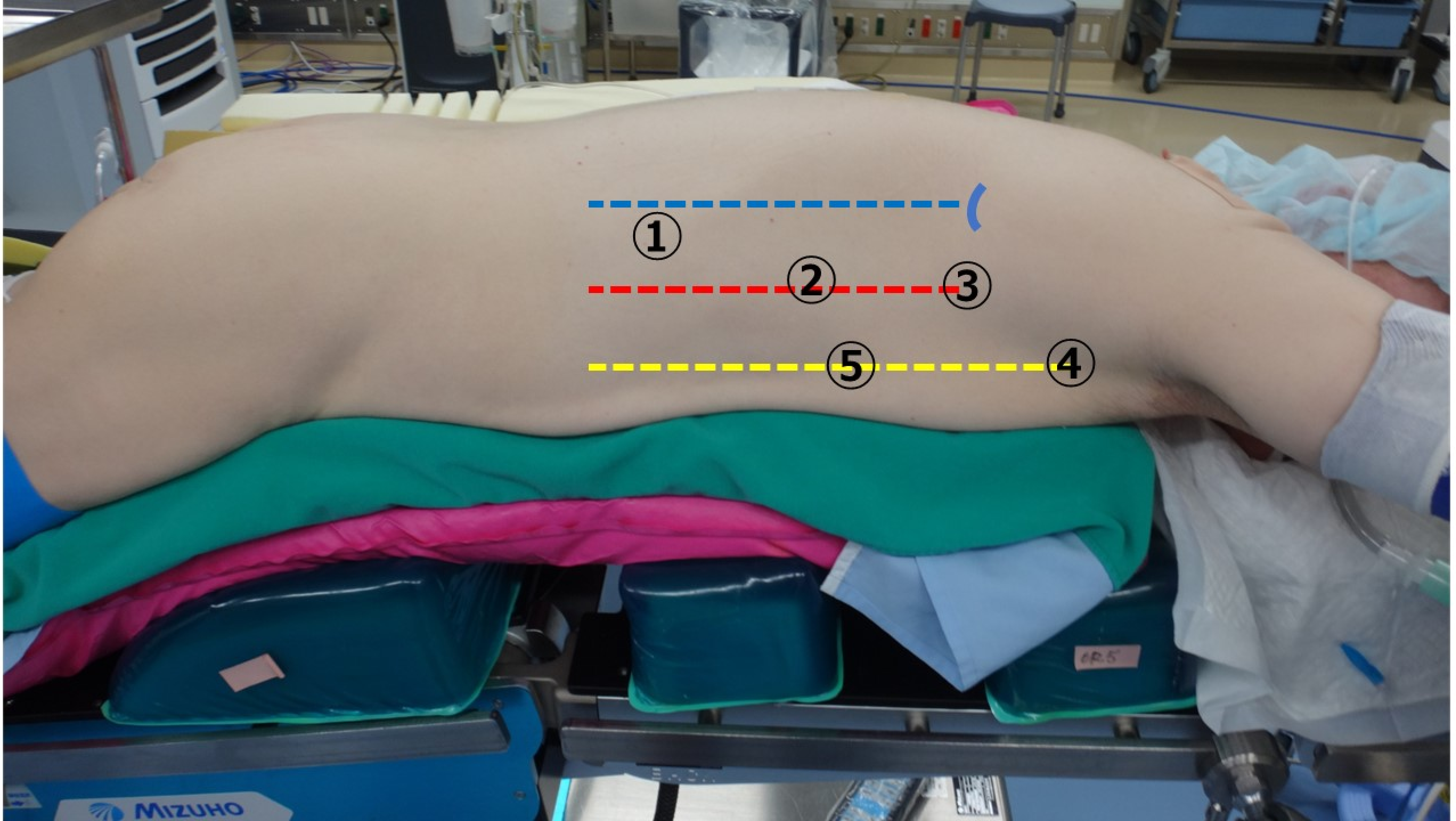
Figure 1: Patient Position and Thoracic Port Placement
①～④: 8-mm da Vinci ports. Numbers indicate arm assignments.
⑤: 12-mm assistant port.
Dashed blue line: scapular line.
Dashed red line: posterior axillary line.
Dashed yellow line: midaxillary line.

Figure 2: Schema of the Thoracic Surgical Procedure
The surgery progresses in the direction indicated by the yellow arrows.

Figure 3: Thoracic dissection
a: Anterior Dissection of the Lower Mediastinum
Resected tissue forming a "curtain" (white arrowhead).
Diaphragm (white *).
Pericardium (black *).
b: Subcarinal Lymph Node Dissection
Inferior margin of the bronchus (white arrowhead).
c: Dissection Around the Right Recurrent Laryngeal Nerve
Right recurrent laryngeal nerve (white arrowhead).
d: Dissection Around the Left Recurrent Laryngeal Nerve
Left recurrent laryngeal nerve (white arrowhead).
Thoracic duct (black arrowhead).
e: Dissection from the Mediastinal Pleura on the Left Wall
Resected tissue forming a "curtain" (white arrowhead).
Gauze placed dorsally to the pericardium at the beginning of the procedure (black *).

Figure 4: Abdominal Port Placement
a. Placement of instruments and scope during small-curvature dissection.
b. Placement of instruments and scope during large-curvature dissection.

Figure 5: Abdominal dissection
a: Division of Short Gastric Vessels from the Lesser Curvature
Left gastric artery stump (black arrowhead).
Short gastric vessels (white arrowhead).
Upper pole of the spleen (white *).
Splenic artery (black *).
b: Division at the Splenic Hilum from the Greater Curvature
Tail of the pancreas (black *).
Gauze placed during lesser-curvature dissection (white *).
Assistant instrument (white arrowhead).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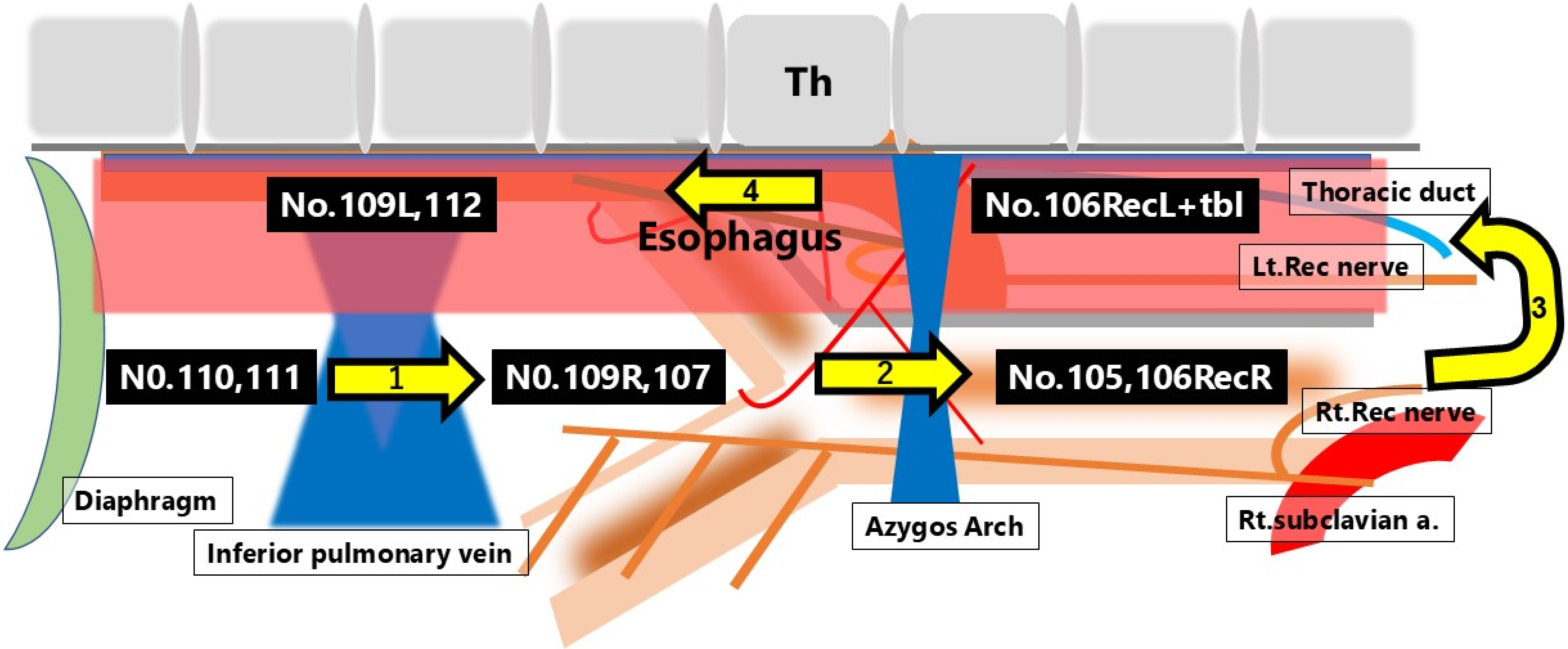

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No.109L,112
4
Esophagus
No.106RecL+tbl
Thoracic duct
Lt.Rec nerve
3
N0.110,111
1
N0.109R,107
2
No.105,106RecR
Rt.Rec nerve
Diaphragm
Inferior pulmonary vein
Azygos Arch
Rt.subclavian a.


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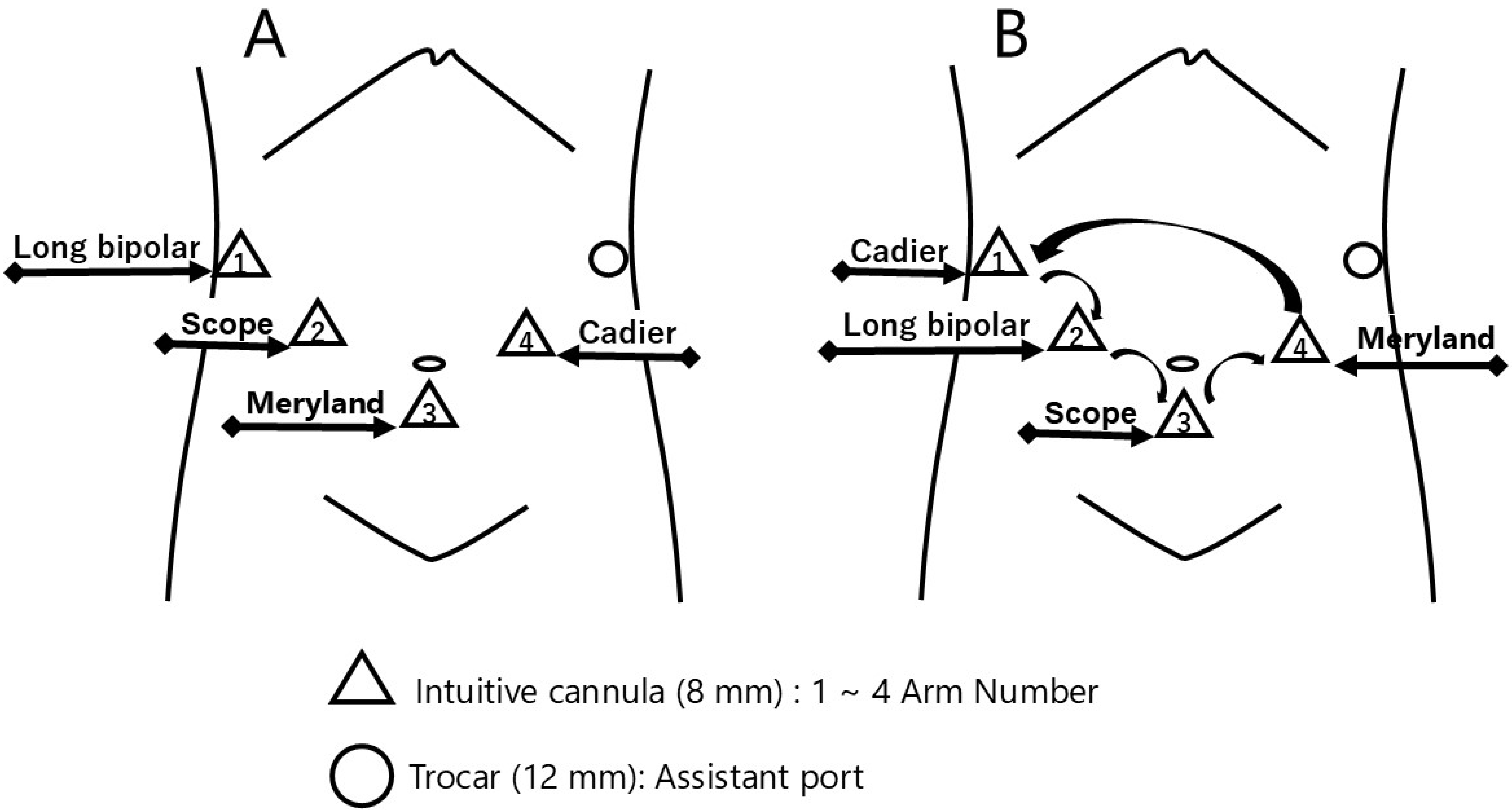
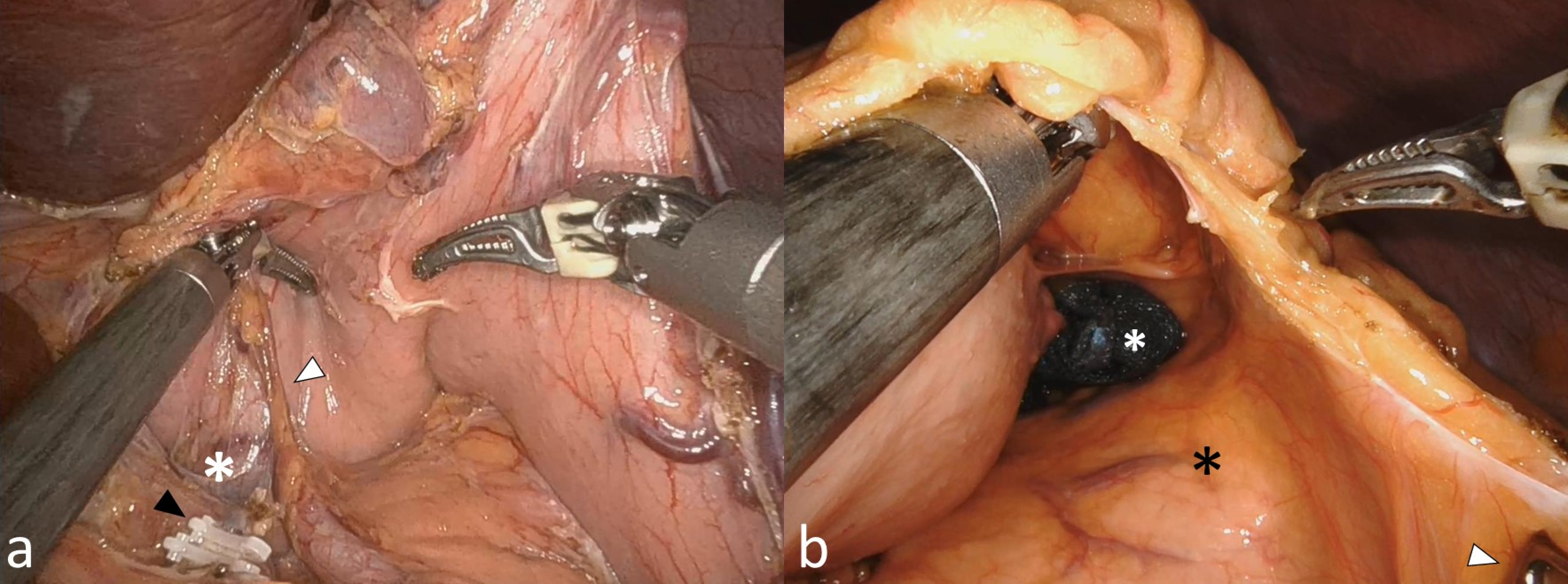

A
Long bipolar
1
Scope
2
Meryland
3
4
Cadier
B
Cadier
1
Long bipolar
2
Scope
3
4
Meryland
Intuitive cannula (8 mm) : 1 ~ 4 Arm Number
Trocar (12 mm): Assistant port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