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ORIGINAL ARTICLE

Mediastinoscopic view of the bronchial arteries in a series of surgical cases evaluated with three-dimensional computed tomography

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Abstract

Background We have routinely performed three-dimensional computed tomography (3-D CT) prior to video-assisted transmediastinal esophagectomy to evaluate the small arteries in the mediastinal operative field. This evaluation would be helpful in performing mediastinoscopic esophagectomy.

Methods Thirty-one patients who underwent transmediastinal esophagectomy with preoperative evaluations by 3-D CT were the study subject. The bronchial arteries depicted by the 3-D CT were classified by their origin and laterality. In 18 of the 31 cases, the surgical video was available and the identification rate in the video was reviewed for each of the categorized bronchial arteries.

Results The detection rates of each classified artery were as follows (abbreviations, detection rate); the intercostal-bronchial trunk (IBT, 22/31), the direct left bronchial artery (LBA, 17/31), the common trunk of bronchial arteries (CTB, 7/31), the direct right bronchial artery (RBA, 2/31), and the ectopic arteries (16/31). The ectopic arteries arose from the aortic arch (11 cases), the right subclavian artery (6 cases) or the left subclavian artery (1 case). The identification rates of IBT, LBA, CTB, RBA and any of the ectopic arteries in the video review were 12/13, 4/8, 3/4, 1/1 and 2/10, respectively.

Conclusions Preoperative 3-D CT was a highly sensitive evaluation for the bronchial arteries encountered during transmediastinal esophagectomy. Orthotopic arteries except for LBA were frequently identified at the predicted sites. Although RBA and CTB were present infrequently, they often flowed into regional nodes at the bilateral bronchi or the tracheal bifurcation and, therefore, should be preoperatively evaluated.

Keywords Esophagectomy · Bronchial artery · Three-dimension tomography · Mediastinoscopy · Transmediastinal

Background

To perform esophagectomy, a surgeon should be familiar with the variations of the bronchial arteries and well-informed about the particular variation of the artery of each individual patient through preoperative evaluation. The anatomical features of the bronchial arteries have a wide variety and a number of literatures have provided information on them [1–9]. The right bronchial artery originating from the intercostal-bronchial trunk (IBT) is perhaps the most familiar one for the esophageal surgeon and it was reportedly detected in 60–85% of cases [1, 2, 4, 7–9]. The right bronchial artery arising from IBT runs dorsal-right side of the esophagus in nearly all cases, while the right bronchial artery as a direct branch of the aorta cross the esophagus ventrally with few exceptions. As for the left bronchial arteries as a direct branch of the aorta, one type of them courses closely to the left side of the esophagus, while the other type runs toward the lung hilum and never approaches the esophagus [1, 3, 4, 9]. These right and left bronchial arteries can share their origins as the common trunk of bronchial arteries (CTB) and the incidence of CTB have been reported

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as 31–52% [1–4, 7]. The bronchial arteries can originate from the subclavian arteries or their branches and their incidence was reported as 4–5% for the right and 0–2% for the left [1, 2, 4, 7].

The level of the ostia of the bronchial arteries in the aorta plays a key role in classifying the bronchial arteries as orthotopic or ectopic; the bronchial arteries originating from the aorta within the segment between the fifth and the sixth vertebra is defined as "orthotopic" and those not included in the above described categories are defined as ectopic [5, 6]. The bronchial arteries originating from the aortic arch have their ostia at various directions in the aorta and typically run in front of the trachea [3, 6].

The anatomy of these variable bronchial arteries are considered as the basic anatomical knowledge required in performing esophagectomy and well-shared among the most expert esophageal surgeons. However, the mediastinoscopic view of the bronchial arteries would be unfamiliar to most esophageal surgeons accustomed to esophagectomy via transthoracic approach. Moreover, the mediastinoscopic operative field is usually narrower than that of transthoracic surgery and an adequate assistance by assistant surgeons is unavailable due to a limited number of port sites. Therefore, a preoperative evaluation for case-to-case variations of the bronchial arteries would deserve special importance to perform video-assisted transmediastinal esophagectomy.

In such backgrounds, we started the routine use of 3-D CT in preoperative evaluation for esophageal cancer patients who plan to undergo transmediastinal esophagectomy. In this study, the preoperative findings of the bronchial arteries in the 3-D CT were summarized and their concordance with the operative findings was verified by surgical video.

Methods

Patients

We reviewed preoperative 3-D CT of 31 patients who underwent transmediastinal esophagectomy from February 2015 to November 2017 in The University of Tokyo Hospital. Among them, a full length of the surgical video was available in 18 patients. The clinicopathological characteristics of the study patients are shown in Table 1.

Imaging protocol of 3-D CT

One hundred ml of iopamidol-370 (Bayer Yakuhin, Osaka, Japan) for patients with body weights of 60 kg or more or 100 ml of iohexol-350 (Daiichi Sankyo, Tokyo Japan) for patients with less than 60 kg was given by 4 ml per second intravenously. Scanning was started as the CT number in the descending aorta reached 350 Housefield Unit.

Table 1 Clinicopathalogical characteristics of patients

Media age (range)	68 (58–84)
Gender (male/female)	28/3
Locus of tumor (Ut/Mt/Lt/Ae)	2/22/5/2
Pathological *T* stage (0/1a/1b/2/3)	1/1/17/5/7
Pathological *N* stage (*N*0/*N*1/*N*2/*N*3)	16/7/5/3

Locus, *T* stage and *N* stage are indicated in accordance with the 10th edition of guidelines by the Japanese Esophageal Society

The following scanning parameters were used; Scan mode: Helical (SHR mode), Helical pitch (beam pitch): 0.806, Gantry rotation time: 0.6 and 0.5 s, Detector configuration: 0.5 mm × 80 and 0.25 mm × 160, Tube voltage: 120 kVp, Tube current: Automatic exposure control was used (Max Current: 300 mA, Min Current; 50 mA). Axial sections (0.25-mm thickness) were reconstructed at 0.25-mm intervals and transferred to a workstation (Ziostation2;Zio Software, Tokyo, Japan).

Thin-section reconstructed CT images were assessed using the paging method at the workstation

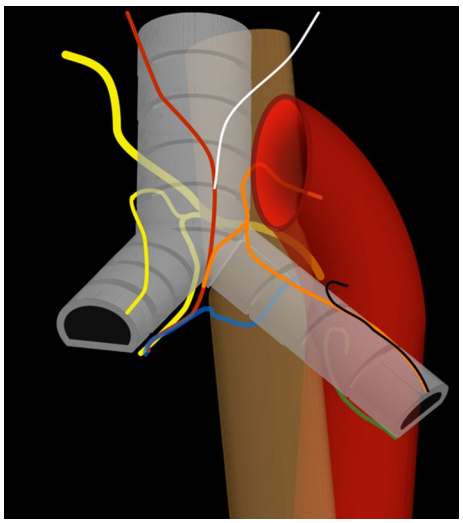

Fig. 1 Variations of the bronchial arteries. (1) Intercostal-bronchial trunk (IBT): yellow, (2) common trunks of bronchial arteries (CTB): not drawn. Common trunk of the following right and left bronchial arteries. (3) Left bronchial artery as a direct aortic branch (LBA): black. (4) Right bronchial artery as a direct aortic branch: blue. (5-1) Bronchial artery originating from the right subclavian artery or its branch (RSCA-BA): red. (5-2) Bronchial artery originating from the left subclavian artery or its branch (LSCA-BA); white. (5-3) Bronchial artery which has its ostia in the aortic arch (Arch-BA);orange. (5-4) Bronchial artery which has its ostia in the lower site of the descending aorta: green. Numbers with a piece parenthesis are corresponding to the numbers that appeared in the Methods section. The course and the laterality of the orthotopic arteries, (1), (2), (3) and (4) are highly constant, while those of ectopic arteries such as (5-1), (5-2) and (5-3) have a wide variety. This figure illustrates the representative courses of the bronchial arteries. The incidence as well as the course of these arteries is highly variable

"Ziostation2:Ziosoft, Inc" to identify bilateral bronchial arteries. To generate 3D simulations, we first created the following five independently segmented volumes using the "multi-volume" function of the workstation; segment 1: the bronchial arteries, segment 2: the aorta, segment 3: the trachea, segment 4: the esophagus, segment 5: the azygos vein. Segments 1, 2, 3 were generated using arterial phase images and segments 4, 5 were generated using venous phase images. These segments were then superimposed to produce surgical intelligent imaging as 3-D simulation. The simulation 3-D image was created by radiologic technologists (technologist staff with 5–15 years of 3-D image creation experience) and consensus with surgeons. The original axial CT images together with the 3-D simulation images were reviewed by four surgeons (authors K.M., K.Y., S.A and Y.S.) and the classification and the interpretation of the bronchial arteries were defined according to the agreement of these surgeons.

Surgical procedure of video-assisted transmediastinal esophagectomy

Our surgical procedure of the transmediastinal esophagectomy was described elsewhere [10, 11]. Briefly, a majority of the upper mediastinal dissections were performed via a small left-sided cervical incision with an assistant of mediastinoscopy. Lymph stations of #105, #106recL, #106tbL and a part of #108 were dissected. The left and posterior sides of the trachea, the aortic arch and the descending aorta, the azygos vein and lymph nodes located at tracheal bifurcation and bilateral bronchi were exposed. Subsequent open cervical procedure and the transhiatal procedure completed the upper and the remnant whole mediastinal dissections. Transhiatal

Table 2 Detection of the bronchial arteries in 31 study patients

Case	Surgical Video	1) IBT	2) CTB	3) LBA	4) RBA	5-1) Arch-BA	5-2) RSCA-BA	5-3) LSCA-BA
1	Available							
2	Available							
3	Available							
4	Available							
5	Available							
6	Available							
7	Available							
8	Available							
9	Available							
10	Available							
11	Available							
12	Available							
13	Available							
14	Available							
15	Available							
16	Available							
17	Available							
18	Available							
19	Unavailable							
20	Unavailable							
21	Unavailable							
22	Unavailable							
23	Unavailable							
24	Unavailable							
25	Unavailable							
26	Unavailable							
27	Unavailable							
28	Unavailable							
29	Unavailable							
30	Unavailable							
31	Unavailable							

Black cell: Detected both by 3-D CT and surgical video, gray cells: detected only by 3-D CT, stripe cell: detected only by surgical video, lateral stripe cell: detected by 3-D CT but surgical video unavailable, blank cell: No detection

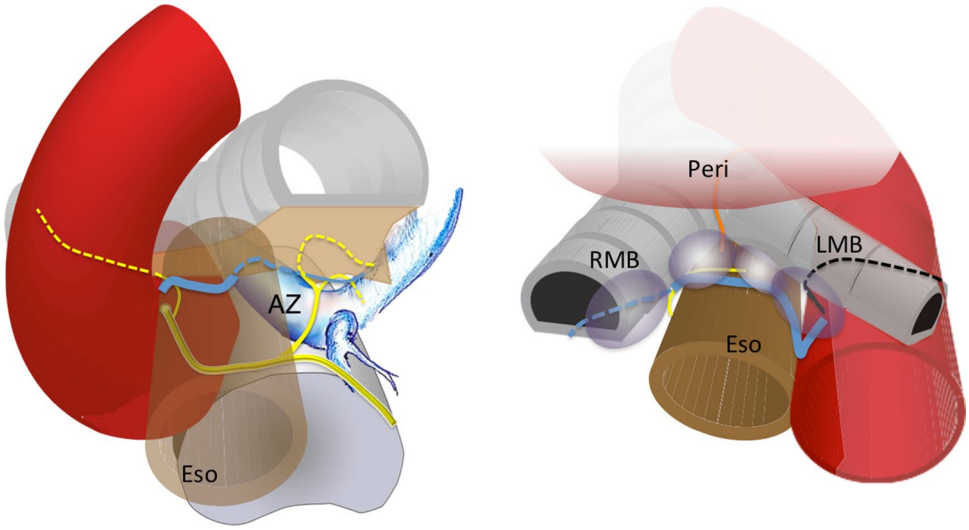

Fig. 2 The operative view of the mediastinoscopy (left: trans-cervical, right: transhiatal) and the sites of the bronchial arteries. IBT courses behind the esophagus (yellow) and branches the right and left bronchial artery. Meanwhile, the right bronchial artery arising from CTB or directly from the aorta usually courses in front of the esophagus (blue). The pre-tracheal branch of the bronchial arteries may be exposed at the tracheal bifurcation. These pre-esophageal tracheal arteries run into the middle mediastinal regional nodes. *AZ* azygos vein, *Eso* Esophagus, *RMB* right main bronchus, *LMB* left main bronchus, *Peri* pericardia

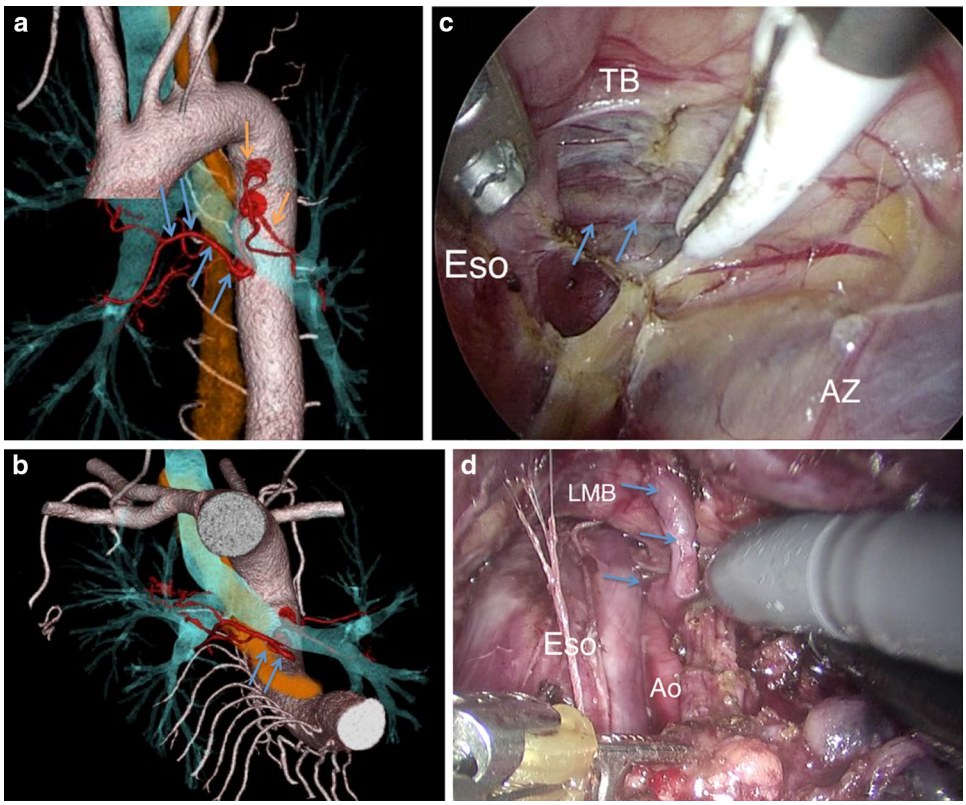

Fig. 3 The 3-D CTs (**a** left anterior oblique view, **b** caudal-cranial view) and screenshots of surgical video (**c** trans-cervical, **d** Transhiatal) of case no. 16. Two bronchial arteries, Arch-BA (**a**, orange arrows) and a CTB branch to the right main bronchus (**a**, **b**, blue arrows) were detected by 3-D CT. Blue arrows in **a**, **b** indicate the corresponding sites of the bronchial arteries exposed as a thick artery in the video screenshots (blue arrows, **c** and **d**, respectively). The peripheral side of this thick CTB branch penetrated the tissue containing subcarinal regional nodes at near the upper limit of the **d** and eventually traversed the esophagus ventrally (**a**, **c**). *AZ* azygos vein, *Eso* esophagus, *TB* tracheal bifurcation, *LMB* left main bronchus

surgical procedure was performed by a conventional laparoscopic approach until it reached the level of the bilateral inferior pulmonary veins and the middle mediastinal dissections were performed mainly by robot-assisted surgery using daVinci S or daVinci Xi system. The radical esophagectomy was completed without transthoracic approach in all cases except for one case of conversion to open transthoracic surgery due to injury on the left main bronchus.

Classification of the bronchial arteries and their interpretations

Both the reconstructed 3-D CT images and the axial CT images were carefully reviewed and the depicted bronchial arteries were classified by their origin and laterality. The principle of classifying the bronchial arteries in this study was primarily orthotopic or ectopic and secondarily the site of their origins and their laterality. The bronchial arteries are classified as ectopic if their ostia in the aorta was cranial to the upper limit of the 5th vertebra or caudal to the lower limit of the 6th vertebra. With these criteria, the bronchial arteries were classified as; orthotopic arteries: (1) IBT, (2) CTB, (3) right bronchial artery directly originating from the aorta (RBA) or (4) left bronchial artery directly originating from the aorta (LBA); ectopic arteries originated from: (5-1) The right subclavian artery or its branches (RSCA-BA), (5-2) The left subclavian artery or its branches (LSCA-BA), (5-3) the aortic arch (Arch-BA) and (5-4) the low descending aorta (Fig. 1). In the following analyses, (5-4) category of the above was included into (3) or (4) category in accordance with its laterality.

The detection rate (depicted cases/all cases of 31) of the artery in each category by 3-D CT was one subject for analysis. Then, the surgical video was reviewed to search the clear exposition of the bronchial arteries. Another study subject was the concordance between the findings of 3-D CT and surgical video. The bronchial arteries depicted in 3-D CT and their operative view in surgical video are introduced with screenshot photos of three representative cases.

Results

The findings of the bronchial arteries by both preoperative CT and surgical video were summarized in Table 2. The detection rates of the (1) IBT, (2) CTB, (3) RBA, (4) LBA, (5-1) RSCA-BA, (5-2) LSCA-BA and (5-3) Arch-BA were 22/31 (71%), 7/31 (23%), 2/31 (6%), 17/31 (55%), 6/31 (19%), 1/31 (3%) and 11/31 (32%), respectively. IBT branched the right and left bronchial artery in 20 and 3 cases, respectively. Except for one IBT in one case (No. 7), all of the arteries identifiable in the surgical video were detected by preoperative 3-D CT (sensitivity: 17/18, 94%). The identification rates in the surgical video of (1) IBT, (2) CTB, (3) RBA detected in the preoperative 3-D CT were 12/13, 3/4 and 1/1, while those of (4) LBA, (5-1) RSCA-BA, 5-2) LSCA-BA and (5-3) Arch-BA were 4/8, 1/3, 0/1 and 2/7, respectively. The sites where the bronchial arteries are frequently exposed are illustrated in Fig. 2.

There were no troublesome hemorrhagic events resulted from injury of these bronchial arteries in the surgeries of all the 31 study cases. Figures 3, 4 and 5 show sets of the preoperative 3-D CT imaging and screenshots of surgical video of three representative cases.

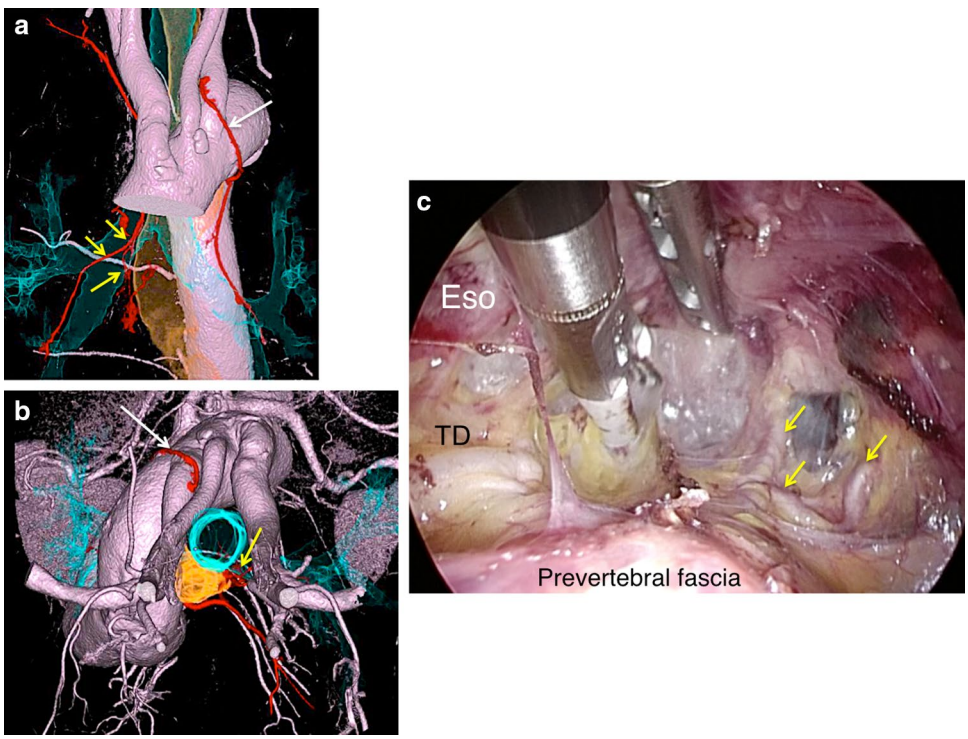

Fig. 4 The 3-D CT (**a** anteroposterior view, **b** cranial-caudal view) and a screenshot of trans-cervical surgical video (**c**) of case no. 13. Two bronchial arteries, IBT (yellow arrows) and LSCA-BA (white arrows) were detected by 3-D CT. Yellow arrow heads in **a** and **b** are indicating the corresponding sites of the bronchial arteries exposed in the video screenshot. The right bronchial artery arising from IBT was exposed in the screenshot of trans-cervical mediastinoscopic video (yellow arrows). *Eso* esophagus, *TD* thoracic duct

Discussion

Transmediastinal esophagectomy has been performed as a less invasive approach for esophageal malignancies and, recently, it is being optimized as a more radical surgery for malignancies by adopting mediastinoscopic approaches [10–13]. Not only the feasibility and the safety, but the minimum invasiveness of video-assisted transmediastinal esophagectomy in comparison with conventional transthoracic procedure has also been reported [10]. With reduced occurrence of pulmonary complications and laryngeal nerve paralysis, transmediastinal esophagectomy would be an attractive surgical procedure of choice especially for elder patients or patients with low pulmonary function. However, both trans-cervical and transhiatal approaches suffer from a narrow surgical field and limited measures of hemostatic manipulation. Once an unintentional injury of blood vessel stains the surgical field, the clear visualization of the minute anatomical structures, e.g., the recurrent laryngeal nerve would be markedly disturbed and a projectile bleeding in a narrow mediastinoscopic operative field would significantly impair the safety of the transmediastinal esophagectomy. Measures to prevent even a small bleeding would be especially important in transmediastinal esophagectomy and they may be better achieved with the precise simulation of the bronchial artery's anatomy.

As with the case of right transthoracic approach, the right bronchial artery originating from the IBT was successfully identified at the invariable site during mediastinoscopic procedures in the majority of cases. Other types of the right bronchial artery, such as one originating from CTB or directly from the aorta in the orthotopic position were comparatively easy to identify in surgical video,

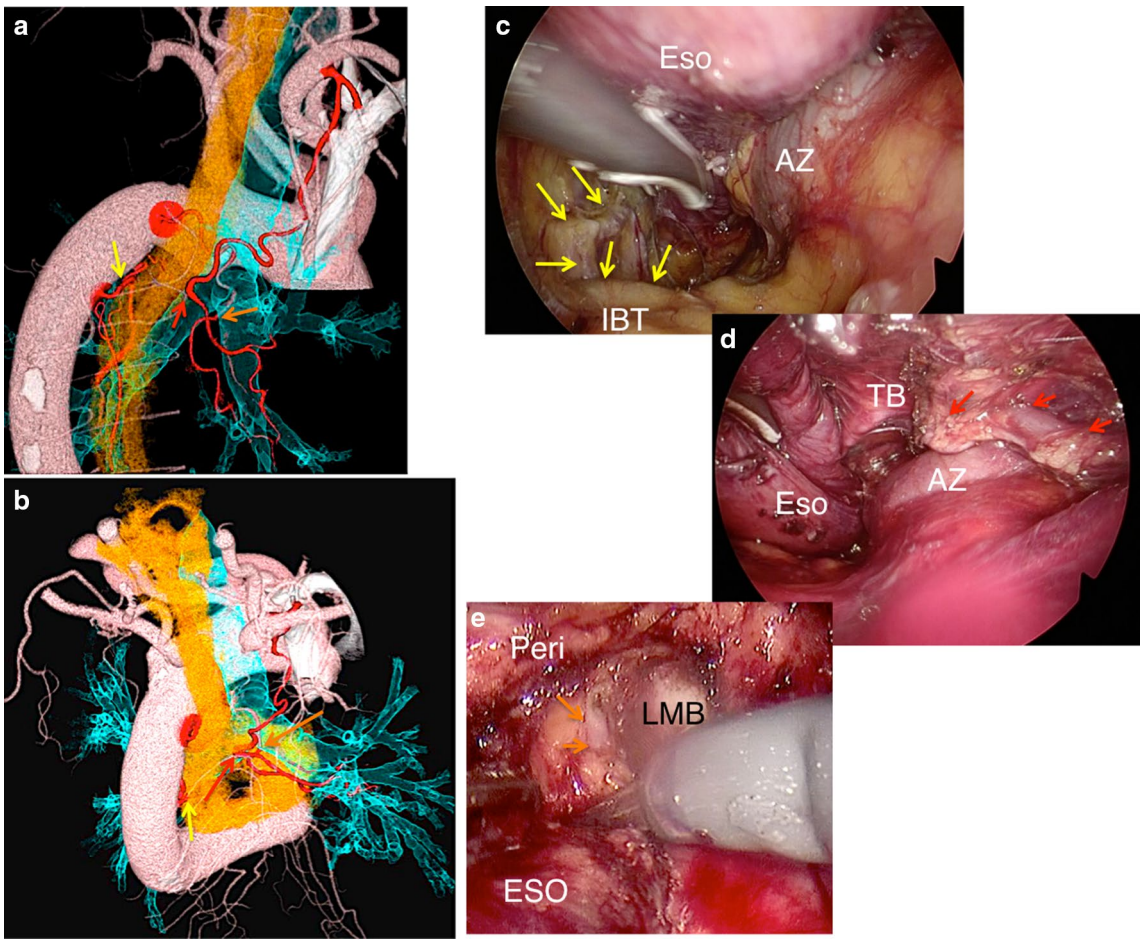

Fig. 5 The 3-D CT (**a** right posterior oblique view, **b** cranio-caudal view) and the screenshots of surgical video (**c**, **d** trans-cervical, **e** transhiatal) of case no. 10. Three bronchial arteries, RSCA-BA (red arrows), Arch-BA (orange arrows) and IBT (yellow arrows) were detected by 3-D CT (**a**, **b**). Arrow heads are pointing to the corresponding sites of the bronchial artery exposed in the video screenshots. The screenshots are showing trans-cervical view of IBT and the left bronchial branch (**c** yellow arrows) and RSCA-BA (**d** red arrows) and transhiatal view of Arch-BA (**e** Orange arrows). *AZ* azygos vein, *Eso* esophagus, *TB* tracheal bifurcation, *LMB* left main bronchus, *Peri* pericardia

because they coursed closely in front of the esophagus. As for LBA, it was identifiable in 4 out of 8 patients, but not in the other 4 patients because it might have never approached the esophagus. As well, the ectopic arteries were not frequently identified during surgery, because most of their courses were either in front of the trachea or closely adherent to the great vessels in the anterior mediastinum.

The most frequent set of the bronchial arteries is reportedly the set with one bronchial artery arising from IBT and one or two orthotopic left bronchial arteries with direct aortic or CTB origins [2, 5]. In our series, this "typical" set was present in only 18 cases out of 31. In some cases of the remaining 13 cases, the ectopic bronchial arteries as their substitutes were thick and hypertrophic and we were able to identify these thick arteries in the video at the sites predicted by preoperative 3-D CT (Figs. 3, 4 and 5). Therefore, the thick bronchial arteries with ectopic origins should not be considered as "abnormal" or "exceptional" [6, 9]. With preoperative 3-D CT, a surgeon can be alert for the variable locations of such ectopic arteries as well as the orthotopic right bronchial arteries arising from either IBT, CTB or the aorta.

Although the subject of this study was rather a small number of patients, it nonetheless contained various patterns of the bronchial artery anatomy. Cumulative surgical experiences with preoperative evaluation of the bronchial artery would support the safety and efficacy of the video-assisted transmediastinal esophagectomy.

Compliance with ethical standards

Ethical statement All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1964 and later versions.

Conflict of interest All of the authors, Mori K, Ino K, Yoshimura S, Aikou S, Yagi K, Nishida M, Okumura Y, Mitsui M, Yamagata Y, Yamashita H, Nomura S and Seto Y, declare that he or she has no conflict of interest.

Informed consent Informed consent or substitute for it was obtained from all patients for being included in the study.

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