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ORIGINAL ARTICLE

Magnetic resonance–thoracic ductography: imaging aid for thoracic surgery and thoracic duct depiction based on embryological considerations

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Abstract
Purpose. We describe the optimal protocol of magnetic resonance–thoracic ductography (MRTD) and provide examples of thoracic ducts (TD) and various anomalies. The anatomical pathway of the TD was analyzed based on embryological considerations.
Methods. A total of 78 subjects, consisting of noncancer adults and patients with esophageal cancer and lung cancer, were enrolled. The MRTD protocol included a long echo time and was based on emphasizing signals from the liquid fraction and suppressing other signals, based on the principle that lymph flow through the TD appears hyperintense on T2-weighted images. The TD configuration was classified into nine types based on location [right and/or left side(s) of the descending aorta] and outflow [right and/or left venous angle(s)].
Results. MRTD was conducted in 78 patients, and the three-dimensional reconstruction was considered to provide excellent view of the TD in 69 patients, segmentalization of TD in 4, and a poor view of the TD in 5. MRTD achieved a visualization rate of 94%. Most of the patients had a right-side TD that flowed into the left venous angle. Major configuration variations were noted in 14% of cases. Minor anomalies, such as divergence and meandering, were frequently seen.
Conclusion. MRTD allows noninvasive evaluation of TD and can be used to identify TD configuration. Thus, this technique is considered to contribute positively to safer performance of thoracic surgery.

Key words Thoracic duct · Magnetic resonance imaging · Esophageal cancer · Lung cancer · Chylothorax

Introduction

The thoracic duct (TD) requires extreme care during thoracic surgery. Its morphology is highly variable, and damage to the TD can result in serious complications such as postoperative chylothorax.[1,2] Therefore, understanding the TD configuration should provide important surgical information. Lymphangiography using an oil-based contrast medium, which is conventionally used

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to image TD configuration, is technically demanding for operators and distressing for patients.[3] Recent advances in magnetic resonance imaging (MRI) systems have enabled clinicians to visualize the TD configuration in a less invasive manner. In this study, we assessed the performance of our MRI technique for TD visualization and analyzed the depicted TD patterns to determine the morphological variations to be considered during thoracic surgery.

Methods

Subjects

The protocol for this research conforms with the provisions of the Declaration of Helsinki. All of the patients enrolled in the present study received ample details about the purpose and advantages of magnetic resonance–thoracic ductography (MRTD), as well as the side effects of MRI. The study was approved by the institutional ethics review board.

A total of 78 subjects, consisting of adults free of cancer ($n = 12$) and patients with esophageal cancer ($n = 65$) and lung cancer ($n = 1$), were enrolled in the study. They consisted of 69 men and 9 women, with a mean age of 61.8 years (range 25–82 years).

MRTD protocol

The TD images were acquired on a 1.5-T MRI system (Symphony; Siemens, Erlangen, Germany) with a three-dimensional (3D)-turbo spin echo (TSE) sequence combined with 2D-prospective acquisition correction (PACE), applying the imaging sequence of magnetic resonance cholangiopancreatography (MRCP) to the mediastinum. Bilateral supraclavicular fossae were compressed using cotton balls 2 cm in diameter for 10 min before examination, and MRI images were obtained with respiratory gating. Before examination, fat meals were not required. We called this technique "thoracic ductography technique by MRI," or MRTD. The imaging protocol used in our institution is shown in Table 1. All patients underwent the same MRTD protocol.

The mediastinum was imaged using the MRTD protocol. The raw MRI data were transferred to a workstation (Zio Station; Amin, Tokyo, Japan) to construct the 3D images of the TD (Fig. 1). In addition to the TD, the spinal fluid, pleura, and gastric juice were depicted. Unnecessary fluids were removed to construct the 3D image of the TD.

Table 1 MRTD imaging protocol, with sequence parameters, used at our institution

2D-Prospective Acquisition CorrEction (PACE)
Scout TR 150 ms (TE: depends on MRI system)
Accept window ±2.0 mm
Position accept window automatic
FOV: 32 mm (for monitoring diaphragmatic movement)
Slice thickness: 10 mm
3D-Turbo Spin Echo (TSE)
TR/TE/ETL = 4000–6000 ms/616 ms/121
Space resolution: 1.3 × 1.3 × 1 mm
Receive BW (Hz/pz): 255
Echo spacing: 9.06 ms
Restore magn.+
Phase oversampling: 10%
Slice oversampling: 14%
Acquisition time: depends on respiratory cycle
FOV: 400 mm
Slice thickness: 1 mm

MRTD, magnetic resonance–thoracic ductography; 2D, two-dimensional; 3D, three-dimensional; TR, repeatitation time; TE, echo time; MRI, magnetic resonance imaging; FOV, field of view; ETL, echo train length; BW, bandwidth

MRTD image analysis

Two investigators visually assessed the imaging performance using the following three-point scale: excellent (the entire TD is clear, and the pathways and shapes can be easily recognized); segmentalized (partially discontinued but the overall structure can be recognized); or poor (entirely or partially not clear, insufficient to recognize the entire duct and shape). Disagreements on evaluation were resolved by three investigators.

The TD configuration was classified into nine types based on location [right and/or left side(s) of the descending aorta, in the lower to middle mediastinum] and outflow [right and/or left venous angle(s)]. Table 2 shows the TD configurations based on the combination of each location and outflow position. Any noteworthy anomaly was carefully documented. The outflow position within 1 cm from the venous angle was regarded as the venous angle opening.

Statistical analysis

Statistical significance of the difference of the frequency of the variation of the TD between the MRTD results and the anatomical consideration was evaluated by a χ^2 test.

Results

The TD was identified on MRTD in all 78 cases as a tubular structure of high signal intensity. The imaging

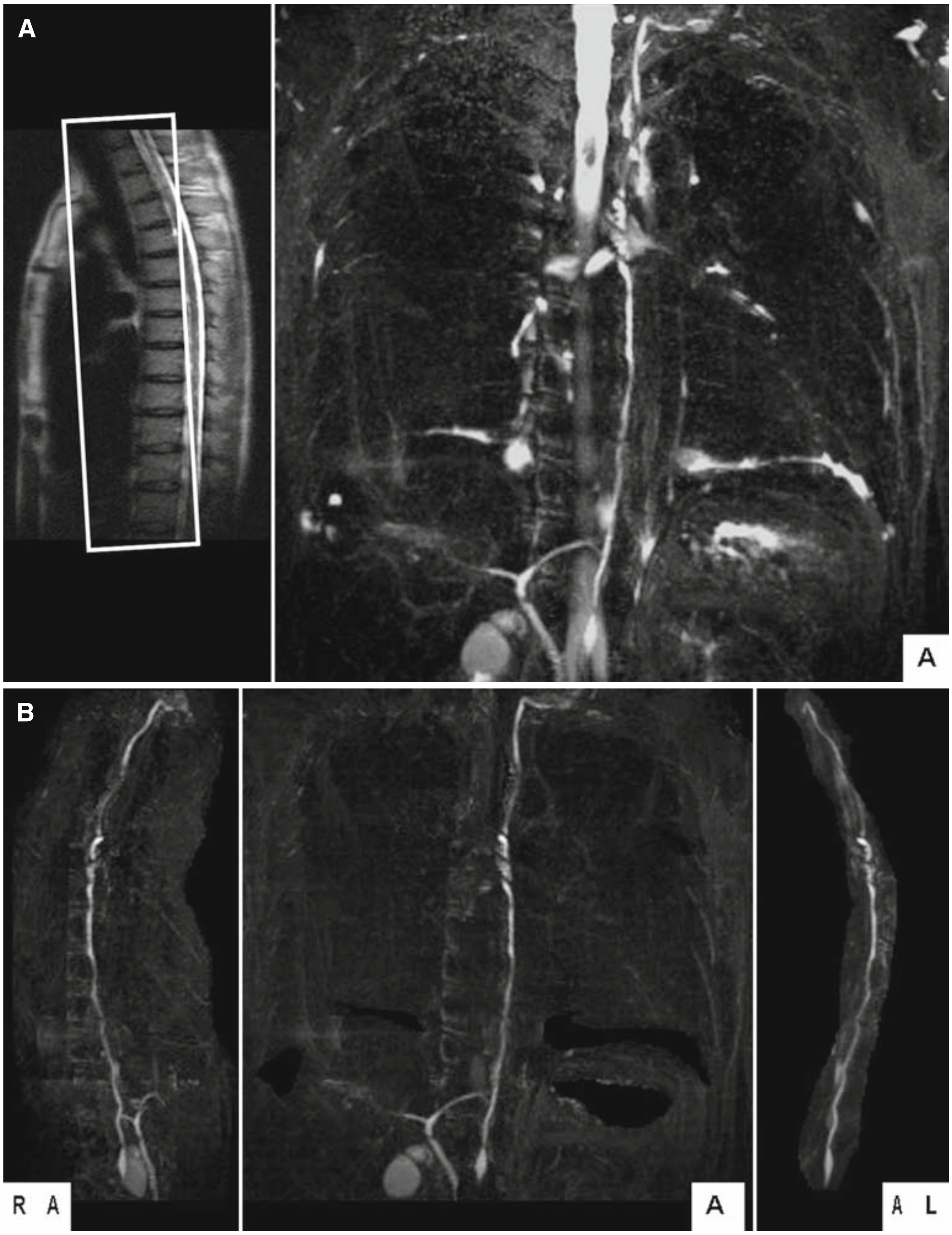

Fig. 1 Noncancer case, type VI thoracic duct (TD), in a 32-year-old man. **A** Image of the mediastinum, outlined by a *white box*. In addition to the TD, note also the spinal fluid, pleura, and gastric juice. **B** Unnecessary fluids were removed to construct the three-dimensional image of the TD. Viewing from multiple angles helps easier understanding of the TD configuration

performance was excellent in 69 cases, segmentalized in 4, and poor in 5. MRTD achieved a visualization rate of 94%. Excluding the latter 5 (poor performance), the remaining 73 cases were categorized according to TD configuration and are illustrated in Fig. 2. The most common configuration was that of type VI, followed by type IX, type III, and types IV and V. the results of the MRTD classification were not different from the anatomical classification (Table 3).

Other minor anomalies included duplication, divergence more than two in the running process, and marked meandering at local regions. Divergence and meandering were frequently seen.

Various anomalies of TDs were identified. The patterns were different in each case, and the location and outflow position varied. Examples are shown in Figures 3–6.

Discussion

The thoracic duct is conventionally visualized by lymphangiography using oil-based contrast medium.[3] However, this method is complex, and there is the risk of pulmonary embolism by the contrast medium; thus, it has been little performed in late years.

Table 2 MRTD classification by location and outflow position

Bilateral TD type
- Two TDs: one located on the left and the other on the right side of the descending aorta
- Type I (bilateral TD with bilateral outflow): right and left TDs flow into the right and left venous angles, respectively
- Type II (bilateral TD with right outflow): right and left TDs join and flow into the right venous angle
- Type III (bilateral TD with right outflow): right and left TDs join and flow into the left venous angle

Right TD type
- Single TD located on the right side of the descending aorta
- Type IV (right TD with bilateral outflow): right-side TD bifurcates with each branch flowing into the right/left venous angle
- Type V (right TD with right outflow): right-side TD flows into the right venous angle
- Type VI (right TD with left outflow): right-side TD flows into the left venous angle

Left TD type
- Single TD located on the left side of the descending aorta
- Type VII (left TD with bilateral outflow): left-side TD bifurcates with each branch flowing into the right/left venous angle
- Type VIII (left TD with right outflow): left-side TD flows into the right venous angle
- Type IX (left TD with left outflow): left-side TD flows into the left venous angle

See also Fig. 2

Table 3 Comparison of MRTD classification and anatomical classification

Type	I	II	III	IV	V	VI	VII	VIII	IX
Okuda ($n = 73$)	0	0	3	2	1	63	0	0	4
Adachi[4] ($n = 261$)	0	0	16	5	4	229	0	0	7

There were no statistically significant differences

Our MRI-based technique allows successful visualization of the TD using a 1.5-T MRI system with the MRCP imaging sequence modified for application to the mediastinum. Specifically, signals from the liquid fractions were emphasized, and other signals were suppressed based on the principle that lymph flowing through the TD appears hyperintense on T2-weighted images. Our technique is safe and does not require the use of any contrast medium. The method was designed primarily to improve TD images, and we named it MRTD. It shows the detailed structure and configuration of the TD under special imaging conditions, one of which is a long echo time (TE), which was set longer to suppress the aortic intensity. Respiratory gating was also employed to reduce artifacts caused by breathing-related movements of the thorax. Furthermore, the bilateral supraclavicular fossae were compressed at the time of imaging to ensure better visualization of the TD. Together, these modifications improved the visualization of TD by MRI by pooling the lymph within the TD. As a result, MRTD achieved a high visualization rate (94%). Furthermore, our MRTD imaging approach not only provides clear pictures but allows detection of various TD anomalies.

The TD develops from symmetrical organs during early embryogenesis. Following the symmetrical development and transverse anastomosis at several locations of the initial TD, part of the duct continues to develop while the other part disappears.[4–7] The upper one-third of the right TD and the lower two-thirds of the left TD disappear; and the remaining lower two-thirds and the upper one-third of each connect to form a single TD.[4,5] Various anomalies can appear at this stage of development. For example, bilateral TDs could occur due to persistence of the lower two-thirds of the left TD (which should have disappeared). Previous attempts of morphological classification of the TD based on this development process have been reported. Adachi et al. classified the TD into nine types[4] based on location and outflow position.

The morphological classification of the TD used in our MRTD was based on that classification. In our classification based on MRI, type VI TD was the most frequently observed (86.3%, 63/73). This type of TD is described as typical in the literature.[3,8,9] Major configuration variations of the TD were detected in 14% of cases.

The MRTD classification was compared with previously reported anatomical classifications, and the frequency of variations was considered. Table 3 shows that the results of the MRTD classification were not different from the anatomical classification adopted by Adachi et al.[4] Adachi et al. confirmed the TD configuration by dissections of 261 cadavers. Because there is no significant difference between the anatomical classification and the MRTD classification, the variation of the TD depicted by MRTD is considered to reflect the anatomical study precisely. Therefore, MRTD is a superior method for grasping TD configuration.

Hayashi and Miyazaki[10] visualized the TD using a 1.5-T MRI system with a fast advanced spin echo (FASE) sequence in synchronization with electrocardiography (ECG). Their report was the first to describe the use of MRI for TD imaging without a contrast medium. They described the TD located on the right side of the descending aorta but did not discuss TD variations. However, the TD has a number of variations.[4,11,12] For example, it is not always located on the right side of the descending aorta, and the aorta may overshadow the TD image. It is difficult to use it as a preoperative examination.

In anticipation of such a possibility, the intensity of the aorta was suppressed in our technique by setting a long TE. Respiratory gating was employed to reduce

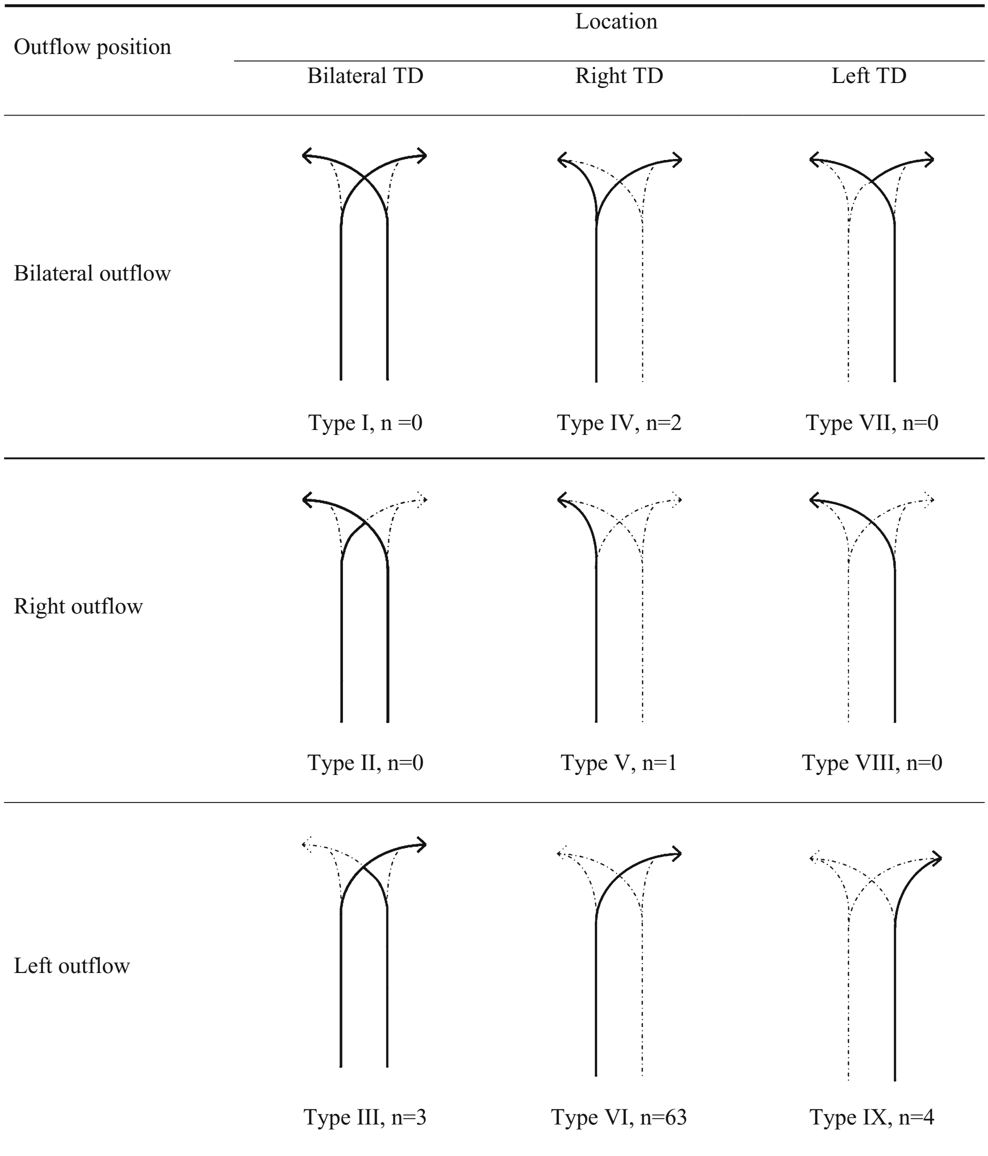

Fig. 2 MRTD configuration and classification

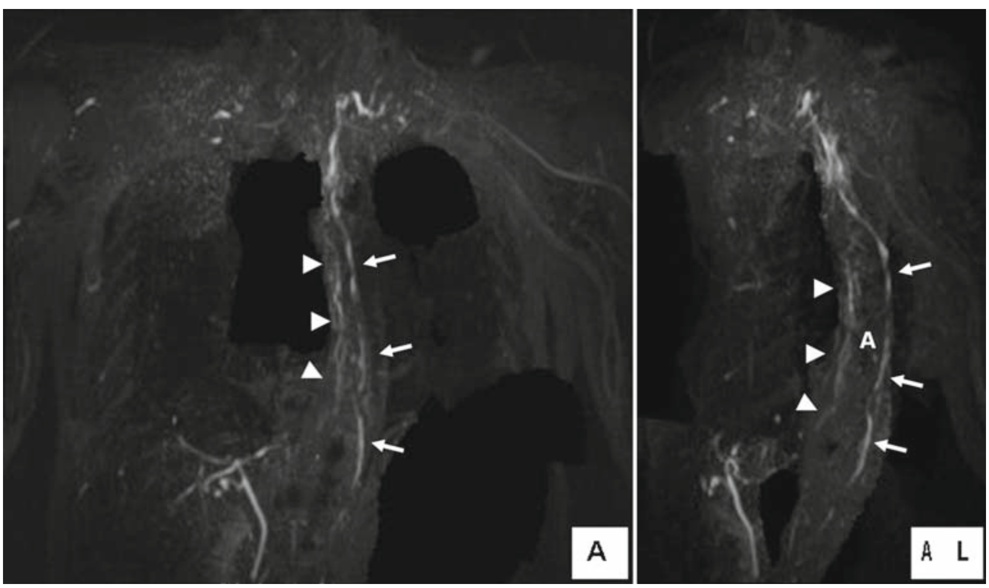

Fig. 3 Case 1. Type III TD (bilateral TD with left outflow). Note the pair of TDs along the right side (*arrowheads*) and left dorsal side (*arrows*) of the aorta. These two TDs can be viewed across the aorta (A) from an oblique view. The two TDs are confluent in the superior mediastinum. The TD flows into the left venous angle. Bilateral TDs type could occur due to persistence of the lower 2/3 of the left TD that should disappear

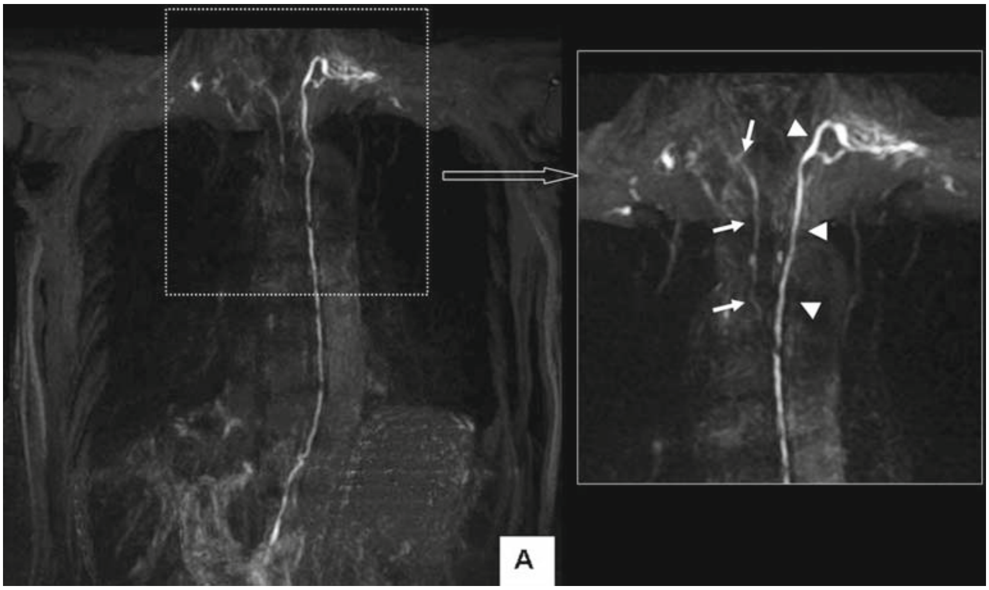

Fig. 4 Case 2. Type IV TD (right TD with bilateral outflow). The TD traveling on the right side of the aorta bifurcates in the superior mediastinum. The right (*arrows*) and left (*arrowheads*) branches each flow into the right and left venous angles, respectively. Right and left TDs in the superior mediastinum could occur due to persistence of the upper 1/3 of the right TD that should disappear

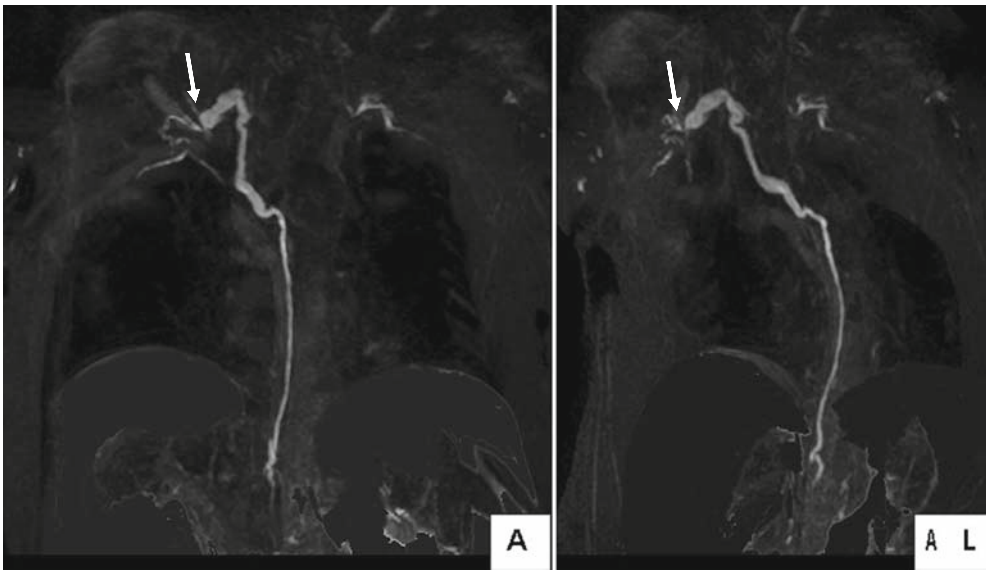

Fig. 5 Case 3. Type V TD (right TD with right outflow). The TD traveling on the right side of the aorta bends to the right in the superior mediastinum. The meandering TD flows into the right venous angle (*arrow*). Right TD with right outflow could occur due to persistence of the upper 1/3 of the right TD that should disappear and disappearance of the upper 1/3 of the left TD

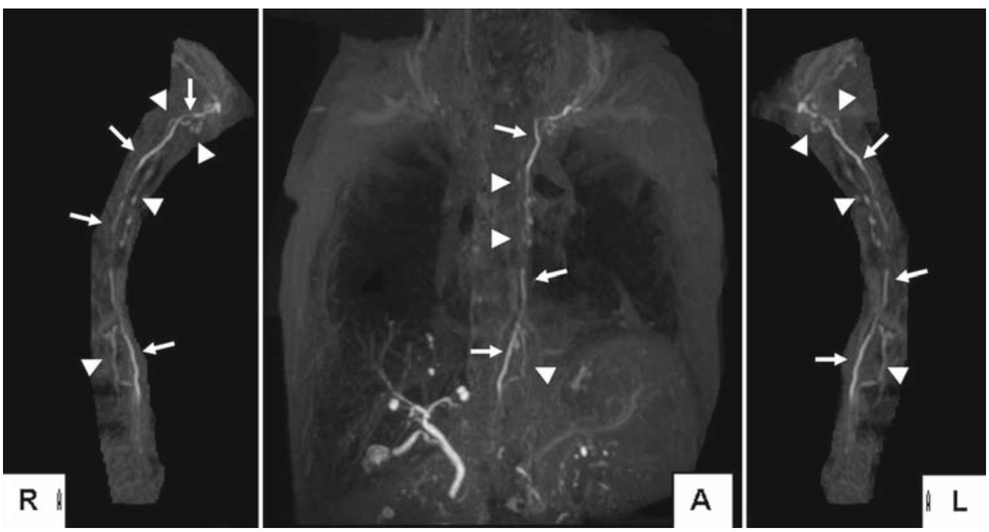

Fig. 6 Case 4. Duplicate type VI TD (right TD with left outflow). Two TDs are observed, both on the right side of the aorta. Magnification and rotation of the TD image shows, one trunk (*arrowheads*) that makes a smooth, circular arch; and the other (*arrows*) takes a tortuous course. Both TDs flow into the left venous angle

artifacts caused by breathing-related movements of the thorax and to depict the details of the TD configuration. These points were different from those of Hayashi et al.'s method.

Minor anomalies, such as divergence and meandering, were frequently seen. Divergence and meandering were different among individual patients. One patient had duplicate type VI TD, in which two right-side TDs were observed and both TDs flowed into the left venous angle. Duplication of a single type of the TD has not been reported to our knowledge.

During thoracic surgery, it is important to foresee an anomalous TD or any variation before surgery. For example, for right open surgery, it is difficult to ligate a left-sided TD. Poor awareness of an anomalous TD may lead to postoperative chylothorax if injury of the TD is left untreated.[2] MRTD allows noninvasive evaluation of the TD for about 15 min from entering the MRI room to leaving it. The contribution of MRTD, which can take effect in a short time, is high when we consider the inconvenience of chylothorax.[13] The imaging performance of MRTD in visualizing the TD was clinically satisfactory. MRTD enables clinicians to establish the configuration, and any anomaly of the TD that might be present. MRTD is a diagnostic imaging procedure that can be used to support safer thoracic surgery and contribute to the prevention of postoperative chylothorax.

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