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Progress in Magnetic Resonance Thoracic Ductography

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Abstract

The thoracic duct is the largest lymphatic vessel in the body and is divided into many types based on its variable morphology and anatomical position. However, it is hard to be imaged because of its spindly structure and covert position. Magnetic resonance imaging provides good prospects for non-invasive detection of the thoracic duct. This article reviews the progress in magnetic resonance thoracic ductography.

Keywords: Thoracic duct; Magnetic resonance imaging; Magnetic resonance thoracic ductography

Introduction

Research history of the thoracic duct

The thoracic duct (TD), as the largest lymphatic vessel, drains approximately three quarters of the body's lymph into the venous system. In general, the thoracic duct derives from retroperitoneal cisterna chyli, ascends along the spine, and terminates in the venous angle, the region of the junction of the internal jugular vein and the subclavian vein. The cisterna chyli, as a conduit for the lipid products of digestion by receiving fatty chyle from the intestines, results from the convergence of two lumbar lymphatic trunks and the intestinal trunk. The cisterna chyli is a dilated sac located posterior to the abdominal aorta on the anterior aspect of the bodies of the first and second lumbar vertebrae.

In 1692 Nuck first identified the lymphatic system by injecting mercury into the lymphatic vessels, and then further characterized the lymphatic system by injecting colored dye into lymphatic vessels. Lymphangiography emerged in the 20th century, but it was an invasive, radioactive, and time-consuming examination that resulted in many complications. Subsequently, radionuclides were used to trace the lymphatic system, but could be a time-consuming operation and were unable to distinguish the anatomical structures between lymphatic vessels and lymph nodes. Since Hayashi et al. [1] succeeded in applying a 3D half-Fourier fast spin-echo sequence with late-diastolic electrocardiographic gating, in magnetic resonance imaging (MRI), to visualize the TD in 1999, subsequent studies have been demonstrating that MRI is a safe, non-invasive and reliable method for TD imaging.

Magnetic resonance thoracic ductography

The TD is filled with slow-moving lymphatic fluid that possesses a long T2 relaxation time, which is the basis of magnetic resonance thoracic ductography (MRTD). So far, sequences of MRTD include heavily T2-weighted turbo spin-echo (TSE) or fast spin-echo (FSE), single shot heavily T2-weighted TSE or FSE, and balanced turbo-field-echo (BTFE). Heavily T2-weighted sequences can enhance the still or slowly streaming fluids in liquid-containing structures and suppress the signal intensity in soft tissues and flowing blood, maximizing the difference in signal intensity between the still or slowly streaming fluids and soft tissues, and flowing blood [2]. TD, as a spindly duct containing slow-moving fluid, is brightly depicted, compared to the dim background, in heavily T2-weighted sequences and maximum intensity projection (MIP) post-processing reconstruction images. Comparatively speaking, single shot heavily T2-weighted TSE or FSE is superior to heavily T2-weighted TSE or FSE, with the advantages of faster imaging speed, as well as higher signal noise ratio and contrast noise ratio, to conduct a thin slice scan and improve spatial resolution. However, it is difficult to use heavily T2-weighted sequences for evaluating the correlation between TD and surrounding structures, such as vessels and vertebrae, because of the suppression in signal intensity of surrounding tissues. A balanced turbo-field-echo (bTFE) sequence is initially applied to coronary artery magnetic resonance angiography. In 2011, Kato et al. used the bTFE sequence to image the TD. Compared with heavily T2-weighted sequences, bTFE can visualize not only the TD but also the structures surrounding the TD. In addition, bTFE can lessen the scanning time to a large extent, which makes patients more comfortable during the scan. With the advantages of shorter scan time and higher tissue contrast of the surrounding

structures, BTFE is superior to single shot heavily T2-weighted TSE or FSE [3-5]. Moreover, three-dimensional (3-D) scanning is superior to two-dimensional (2-D) scanning. This is because 2-D scanning requires a slice thickness of at least 3 mm, in which the motion and respiration of patients are more likely to cause artifacts than 2-D scanning with a thinner slice thickness (less than 1 mm) and a higher spatial resolution. The TD is depicted clearest with respiratory gating in the supine position and at the same time the subject feels most comfortable [6].

The cisterna chyli is identified on MRTD as a dilated sac, of high signal intensity, with a variety of shapes in the retroperitoneum. Shapes of the cisterna chyli found on MRTD include tubular (or linear), plexiform, deltaic, beaded, and triangular, of which the tubular configuration is the most common [7]. Normally, the length of the cisterna chyli is 26.0 ± 10.5 mm, and ranges from 10.2 mm to 55.0 mm. The transverse diameter averages 5.0 ± 2.1 mm, ranging from 2.0 mm to 12.9 mm, and the anteroposterior diameter is 5.1 ± 2.1 mm, ranging from 2.0 mm to 10.9 mm. The TD is identified on MRTD as a tubular structure of high signal intensity ascending along the spine, occasionally with interruption of continuous high signal intensity, due to the spontaneous and rhythmic contraction of the TD. Normally, the transverse diameter of the TD is 3.7 ± 0.4 mm, ranging from 1.9 mm to 6.9 mm, and the anteroposterior diameter of the TD is 3.3 ± 0.4 mm, ranging from 1.4 mm to 6.7 mm [8]. In addition, a fatty meal can enhance lymphatic fluid production and enlarge the TD. Therefore, the TD can often be better delineated at 46 h after the intake of a fatty meal [9,10].

Application of MRTD

MRTD can be applied to identify TD configuration before the operation and plays a critical role in safer performance of thoracic surgery [11]. Preoperative MRTD is helpful to prevent TD injury, for example, in esophagectomies [12] and posterolateral thoracotomy of mediastinal cystic lymphangioma connected to the TD [13]. In 2009, Okuda et al. studied MRTD in 78 subjects. After excluding subjects with poor MRTD performance, the remaining 73 cases were categorized according to TD configuration. As a result, the results of the MRTD classification were no different from the anatomical classification [11]. In general, the incidence rate of postoperative chylothorax and chyle leakage after conducting esophagectomies is 0.4%2.6%. In 2011, Kato et al. demonstrated that preoperative imaging of TD was useful for preventing postoperative chylothorax and chyle leakage. Kato et al. introduced preoperative imaging of the TD, before conducting esophagectomies in more than 100 subjects, and no postoperative chylothorax or chyle leakage occurred [12]. In 2016, Kim et al. performed MRTD in 3 patients with lymphangioma and found that MRTD was helpful for confirmation of continuity of lymphangioma with the TD in cases of lymphangioma. Kim et al. found that lymphangioma displayed a fluid-filled cystic mass with high signal intensity on T2-weighted images, and low signal intensity on T1-weighted images. In addition, in 2 of the 3 patients, MRTD showed that the lymphangioma had a definite connection with the TD. On the basis of the preoperative MRTD findings, one of the patients underwent posterolateral thoracotomy, and at the same time had the TD ligated during the operation, resulting in resection of the mass without postoperative chylothorax or chyle leakage [13].

MRTD can be used to identify leakage sites in cases of postoperative chylothorax and chyle leakage, chylothorax and chyle leakage caused by Gorham disease [13], trauma, lung lymphangioleiomyomatosis, non-Hodgkin's lymphoma etc. [14]. Chylothorax and chyle leakage are identified based on the axial and coronary sequences of MRTD and the reconstructed maximum intensity projection (MIP). In 2016, Kim et al. described MRTD findings of postoperative chylothorax and chyle leakage, in 6 patients, that occurred after lobectomy for lung cancer, after esophagectomy for esophageal cancer, and after mass excision for lipoma. The chyle leakage site was identified on MRTD in 4 patients, but it was not identified in the remaining 2 patients. Imaging showed the pleural effusion to be continuous into the mediastinum between the aorta and azygos vein and leakage sites in the TD. In addition, they also described MRTD findings of Gorham disease in a 63-year-old female with idiopathic chylothorax. Gorham disease is a rare disease, characterized by osteolysis associated with the uncontrolled proliferation of intraosseous thin-walled and distended vascular or lymphatic channels. Imaging showed abrupt discontinuation of the TD with dispersion of chyle into the mediastinum, suggesting leakage around the cisterna chyli. There were also multiple mottled osteolytic lesions, within the vertebral body, that showed high T2 signal intensity representing dilated lymphatic channels [13]. In 2013, Yu et al. depicted MRTD findings of chylothorax and chyle leakage, in 7 patients, that occurred in trauma, lung lymphangioleiomyomatosis, non-Hodgkin's lymphoma, etc. The chyle leakage site was identified on MRTD in 5 patients, but it was not identified in the remaining 2 patients. The leak sites of the TD were identified by finding chylomas or meshworks of tiny lymphatics. A chyloma meant that chyle ran out from the lymphatics or the TD through the leak, locally accumulated in the posterior mediastinum and then formed a cyst-like structure filled with chyle until the mediastinal pleura ruptured. The leak sites of the TD were irrelevant to diameters of the TD and the volume of pleural effusion [14].

MRTD can also be used to find distended TDs such as in patients with active filarial infection, alcoholic cirrhosis [6], or portal hypertension [8]. Filariasis is a disease endemic to tropical and subtropical areas that is caused by infections with Brugia timori, Brugia malayi, or W. bancrofti. The adult worms live in the lymphatics throughout the body and cause extensive lymphangiectasis by obstructing lymph flow. Filariasis is the most common cause of acquired lymphedema. In 2005, Ahn et al. described CT and MRI findings in a patient with filariasis that was characterized by diffuse lymphangiectasi [15]. In 2003, Takahashi et al. measured the maximum TD diameter in 23 healthy volunteers and 113 patients. Takahashi et al. found that the maximum TD diameter was 6.98 ± 2.77 mm in alcoholic cirrhosis, 4.12 ± 1.51 mm in nonalcoholic cirrhosis, 3.60 ±0.80 mm in chronic hepatitis, 3.76 ± 1.10 mm in malignancy, and 3.74 ± 0.81 mm in healthy volunteers. In addition, the maximum diameter of TD in alcoholic cirrhosis was significantly greater than in other groups ($p<0.01$) [6]. In 2010, Yu et al. measured

the transverse diameter of TD in 57 healthy volunteers, 14 patients with portal hypertension caused by chronic hepatitis B or Budd-Chiari syndrome, and 26 patients with the common bile duct obstruction caused by biliary stones, choledocholithiasis, carcinoma of the pancreatic head, or cholangiocarcinoma. Yu et al. found that the transverse diameter of TD was 4.8 ± 0.4 mm in portal hypertension, 3.7 ± 0.3 mm in common bile duct obstruction, and 3.6 ± 0.1 mm in healthy volunteers. In addition, the transverse diameter of the TD in portal hypertension was significantly greater than in other groups ($p<0.05$) [8].

MRTD can be used to discover and characterize the pathogenetic mechanisms of primary lymphedema and idiopathic lymphedema by showing the TD. For example, in 2012, Hara et al. used MRTD to examine nine patients with primary lymphedema of whom five were in early-onset group and four were in late-onset group, and discovered and demonstrated that the pathogenetic mechanisms of primary lymphedema seen in early-onset patients were different from those found in late-onset patients. Hara et al. found that the TDs of four patients in the early-onset group could not be visualized, but the TDs of patients in the late-onset group were all normally visualized. In addition, three patients in the late-onset group had episodes of trauma near the areas that would later be affected by lymphedema in half a year before the onset of edema. So, primary lymphedema seen in late-onset patients might be classified as traumatic lymphedema [16]. In 2012, Hara et al. demonstrated that deformity of the TD might be one of the causes of idiopathic lymphedema by using MRTD on two patients with idiopathic lymphedema in whom anomalies of the TD were all detected [17].

Summary

MRTD is a safe, reliable, and non-invasive method for visualization of the TD. At 46 h after the intake of a fatty meal, using three-dimensional BTFE with respiratory gating in the supine position for visualizing the TD is the best method for MRTD. At present, MRTD has been applied to identify the TD configuration before surgery, find the site of chylothorax occurrence, and study diseases accompanied with anomaly of the TD.

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