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Evaluation of Esophageal Peristalsis in Patients with Esophageal Tumors: Initial Experience with Cine MR Imaging

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We evaluated esophageal peristalsis in patients with esophageal tumors by cine MR using steady-state free precession (SSFP) sequence and correlated the alteration of the esophageal peristalsis with clinical symptoms and tumor stages. Thirteen patients with pathologically proven esophageal tumors, including 12 esophageal cancers and one submucosal leiomyoma, underwent cine MRI using true fast imaging with steady precession (trueFISP) sequence, which is one SSFP sequence, after contrast-enhanced MR scanning for clinical purposes. A total of 120 serial images were obtained within 60 s through the plane along the long axis of the esophagus while patients chewed gum. The serial trueFISP images were evaluated for the presence, frequency, speed of progression, and passage of peristalsis through the tumor. The data from cine MRI were compared with clinical symptoms and tumor stages. Peristalsis was clearly identified in all patients. Seven patients with complete interruption of peristalsis had dysphagia; one with partially impaired peristalsis could intake solid foods with discomfort; and two with partially impaired peristalsis and three with preserved peristalsis remained asymptomatic. Patients with complete or partial interruption of peristalsis had Stage T3 or T4 esophageal cancer. In conclusion, trueFISP cine MR imaging enables direct visualization of esophageal peristalsis in relation to esophageal tumors. Complete interruption of peristalsis causes dysphagia, whereas partial interruption of and preserved peristalsis usually do not cause digestive problems. Interruption of peristalsis may indicate impaired muscle function caused by invasion of advanced esophageal cancers.

Keywords: *cine MR, peristalsis, esophageal tumor, esophageal cancer*

Introduction

The esophagus has a downward contractile movement called peristalsis, which is regulated by the autonomic nervous system and is indispensable for conveying ingested food or fluid. Impairment of peristalsis can have various etiologies, including esophageal tumors, achalasia, and collagen diseases, such as progressive systemic sclerosis or dermatomyositis, and usually results in dysphagia. Dysphagia is the initial symptom in 90% of cases of

esophageal cancer.¹ In this condition, impaired peristalsis may be related to dysfunction of the smooth muscles in the proper muscle layer caused by extension of the cancer.

To evaluate the motility of the esophagus, conventional X-ray fluoroscopy using barium suspension as oral contrast remains the standard technique. However, this technique usually demonstrates the passage of oral contrast rather than peristalsis, and patients with dysphagia are commonly at high risk of aspiration into the lungs. Manometry is a recently developed technique that can indirectly evaluate esophageal peristalsis by measuring the intraluminal pressure of the esopha-

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gus.² However, this method requires the examinee to swallow a thick catheter and is occasionally difficult to perform in patients with severe stenosis or obstruction.

As a result of recent advances in ultrafast MR imaging, cine MR imaging has enabled direct visualization of various kinds of movement in the human body. Steady-state free precession (SSFP) sequencing is one ultrafast technique, and its utility in demonstrating rapid movement, such as swallowing, or very subtle movement, such as uterine peristalsis, has been reported.³⁻⁵ However, to the best of our knowledge, there has been no report that investigated esophageal peristalsis using cine MR with this sequence. If cine MR can demonstrate esophageal peristalsis, it may also enable evaluation of muscular involvement by the tumor, an important prognostic factor.⁶

We evaluated esophageal peristalsis in patients with esophageal tumors by cine MR utilizing SSFP sequence and correlated the alteration of the esophageal peristalsis with clinical symptoms and tumor stages.

Materials and Methods

Our study population included 13 patients with pathologically confirmed esophageal tumors, including 12 esophageal cancers and one submucosal leiomyoma. Although the present study was conducted for 14 patients, cine MR could not be performed in one patient with advanced cancer who had difficulty in swallowing even his own saliva. Written informed consent was obtained from all patients prior to MR study, and approval was granted by the Institutional Review Board of Kyoto University Hospital.

In all patients, cine MR imaging was performed after ordinary MR scan for clinical purposes. No patient received chemo- or radiation therapy at the time of MR study. Seven patients underwent surgery within 2 weeks after MR imaging, while six underwent chemoradiation therapy. In patients treated surgically, pathologic stages of the esophageal cancers were determined according to UICC/TNM classification (Table 1). In patients treated with chemoradiation therapy, clinical stages were determined according to findings on computed tomography and endoscopic ultrasonography. In all patients, the circumference of the esophageal tumor was acquired by reviewing the endoscopic findings.

Examinations were obtained on a 1.5T machine (Magnetom Symphony, Siemens, Erlangen, Germany) equipped with high-performance gradients

Table 1. International Union Against Cancer (UICC) TNM classification of esophageal cancer

T stage	TNM/UICC classification
1a	Invasion within the lamina propria
1b	Invasion within submucosal layer
2	Invasion into the muscularis propria
3	Invasion to the adventitia
4	Invasion into adjacent structures

(30 mT/m). In 12 patients with thoracic esophageal tumor, a phased-array body coil was used to receive data. In one patient with cervical esophageal tumor, a head/neck surface coil was used. Prior to cine MR imaging, to define anatomy and evaluate the local stage of the esophageal tumors, T₂-weighted and contrast-enhanced T₁-weighted images with axial and sagittal or oblique sagittal plane were obtained along the long axis of the esophagus. T₂-weighted images were obtained with half-Fourier acquisition single-shot turbo spin-echo (HASTE) sequence. Contrast-enhanced T₁-weighted images were obtained following intravenous administration of 0.1 mmol/kg gadolinium, utilizing 3D volumetric interpolated breath-holding examination (VIBE) sequence with fat suppression.

Cine MRI was performed using true fast imaging with steady precession (trueFISP) technique, which is one SSFP sequence. Scan parameters for trueFISP sequencing included repetition time (TR) 3.3 to 4.2 ms; echo time (TE) 1.65 to 2.1 ms; flip angle (FA) 70°; field of view (FOV) 250 mm²; matrix 128 × 128; and slice thickness 6.0 mm. Fat saturation technique was not applied. During cine MR imaging, a total of 120 serial images were obtained within 60 s in a single slice of the plane along the long axis of the esophagus that included the tumor. When the esophageal course could not be demonstrated in a single slice, a slice was selected to include the esophageal tumor and normal esophagus as long as possible. Before starting cine MR imaging for peristalsis, cine MRI of the same protocol was performed under natural breathing. Then, patients were required to chew gum and swallow their saliva during cine MRI.

The serial trueFISP images were played at two- to six-fold the speed of cine mode and independently reviewed by 2 radiologists. The readers were blinded to clinical and surgical stage of the esophageal tumors and clinical symptoms of the patients. The readers initially evaluated for presence of tumor and length and thickness of tumor on static T₂-weighted and contrast-enhanced T₁-weighted images. Then, on cine MR, they eval-

uated presence or absence of peristalsis, which was defined as downward movement of transient stricture or focal contraction of the esophagus. When peristalsis was recognized, its frequency, speed of progression, and interruption by tumor, and the presence of dilatation of the esophageal lumen above the tumor were evaluated. When peristalsis was recognized below the tumor, it was considered to be preserved. When the tumor could not be recognized on cine MR imaging, location of the tumor was referenced on contrast-enhanced MR images. Discrepancies between the results of the 2 readers were resolved by consensus.

Data analyzed from esophageal motility was compared with the clinical symptoms of the patients. When the patients had dysphagia, the grade of dysphagia was described by whether they could ingest solid food, liquid food, water, or nothing at all. Results from cine MR imaging were also compared with the pathologic stages in patients treated surgically and the clinical stages in patients treated with chemoradiation therapy. Because the number of subjects was limited, statistical analysis was not performed concerning the progression speed and frequency of peristalsis.

Results

Cine MR during natural breathing showed no peristaltic movement in the esophagus, but cine MR imaging during gum chewing allowed identification of esophageal peristalsis in all patients. Table 2 summarizes the results of cine MR imaging with regard to location, length, thickening, circumference, and stages of esophageal tumor, treatment, and clinical symptoms of the patients.

Seven patients with thoracic esophageal cancer showed complete interruption of peristalsis at or above the level of the tumor. In four of these seven, the esophageal lumen above the tumor was markedly dilated when peristalsis approached, and esophageal peristalsis subsequently diminished in the wall of the dilated esophagus (Fig. 1). In 3 patients, esophageal peristalsis diminished at the level of tumor without causing dilatation of the lumen. Three patients showed partially interrupted peristalsis at the level of the tumor. In these patients, esophageal cancers were localized within the posterior wall, where peristalsis was interrupted by the tumor, while peristalsis in the anterior wall was uninterrupted (Fig. 2). In the remaining 4 patients, esophageal peristalsis was totally preserved, and continuous peristalsis was observed through the level of the tumor (Fig. 3).

The mean progression speeds of peristalsis in

Table 2. The results of cine MR imaging in correlation with tumor stages and clinical symptoms

Patients	Diet status	Tumor stage	Location	Circumference	Length (mm)	Thickness (mm)	Peristalsis on cine MR	Luminal dilatation	Treatment
1	not at all	T3 cancer	Mt	3/4	82	16	completely interrupted	+	Surgery
2	water	T3 cancer	Lt	all	39	18	completely interrupted	-	Surgery
3	solid foods	T3 cancer	Lt	1/3	70	15	partially interrupted	-	Surgery
4	solid foods	T3 cancer	Lt	1/3	38	10	partially interrupted	-	Surgery
5	solid foods	T3 cancer	Ce	1/2	37	13	partially interrupted	-	Surgery
6	solid foods	T1b cancer	Mt	1/2	20	7	preserved	-	Surgery
7	solid foods	Leiomyoma	Mt	submucosal	30	14	preserved	-	Surgery
8	liquid food	T3 cancer	Mt	all	43	24	completely interrupted	+	CRT
9	not at all	T4 cancer	Ut-Mt	all	63	24	completely interrupted	+	CRT
10	not at all	T4 cancer	Mt	all	92	20	completely interrupted	+	CRT
11	liquid food	T4 cancer	Ut	all	52	22	completely interrupted	-	CRT
12	liquid food	T3 cancer	Mt	all	85	18	completely interrupted	-	CRT
13	solid foods	T1b cancer	Ut-Mt	1/2	32	5	preserved	-	CRT

Abbreviations CRT; chemoradiation therapy

Fig. 1. A 55-year-old man with advanced esophageal cancer in the middle thoracic esophagus. The patient had difficulty even in liquid intake. A image from cine MRI (**a**) reveals markedly irregular thickening of the esophageal wall (arrows). On sequential images of cine MRI (**b**, **c**), peristalsis is interrupted above the tumor. The esophageal lumen is completely obstructed by tumor, and the proximal lumen become dilated when peristalsis (arrowheads) approached. Histologic examination following the surgery revealed the tumor invading as far as the adventitia (Stage pT3).

Fig. 2. A 64-year-old man with esophageal cancer in the lower thoracic esophagus. The patient had no problem in diet intake. On sequential images of cine MRI (**a-c**), the esophageal cancer was depicted as focal thickening of the posterior wall of the esophagus (arrows). Peristalsis in the posterior wall (arrowheads in **a**, **b**) is interrupted at the tumor, while peristalsis in the anterior wall (arrowheads in **a-c**) is preserved. Histopathologic examination revealed that the tumor did not exceed half of the circumference, although it invaded as far as the adventitia of the esophagus (Stage pT3).

patients with complete interruption, partial interruption, and preserved peristalsis were 16.4 ± 2.2 cm/s, 28.3 ± 2.9 cm/s, and 27.8 ± 4.0 cm/s, respectively. The mean frequencies of peristalsis in patients with complete interruption, partial interruption, and preserved peristalsis were 8.6 ± 2.4 , 6.3 ± 0.5 , and 7.0 ± 2.6 , respectively.

Seven patients with completely interrupted

peristalsis had dysphagia. In four with luminal dilatation on cine MR imaging, three could not ingest even liquid, and only one could ingest liquid food. Esophageal cancers in these 4 patients were Stages T4 ($n=3$) and T3 ($n=1$). Three patients without luminal dilatation could intake liquid, but not solid food. All of these had esophageal cancer of Stage T3.

Fig. 3. A 60-year-old man with esophageal cancer in the upper thoracic esophagus. The patient had no problem in diet intake. On post-contrast T₁-weighted images with 3D-volumetric interpolated breathholding examination (**a**), the esophageal tumor is demonstrated as focal enhancement of the esophageal wall (arrows). On sequential image of cine MRI (**b-d**), the peristaltic movement (arrowheads) can surge over the tumor. At pathologic examination, the tumor was confined within the submucosal layer (Stage pT1b).

In 3 patients with partially interrupted peristalsis, two had no problem in diet intake and another patient could ingest solid food with discomfort. All of these patients were treated surgically and had esophageal cancers of Stage T3 that occupied less than half of the esophageal circumference.

Three patients with preserved peristalsis also had no problem in diet intake. Esophageal tumors in these three included leiomyoma ($n=1$) and esophageal cancer of Stage T1b ($n=2$). Surgery was performed in one patient with T1b cancer and the patient with leiomyoma, which was found to be confined within the submucosal layer at pathologic examination.

Discussion

The current study shows that cine MR with contrast enhancement can successfully demonstrate esophageal peristalsis. Study of manometry in a large number of healthy volunteers has reported that the progression speed of esophageal peristalsis ranges from 1.3 to 5.7 cm/s.² The mean progression speed in the upper to middle esophagus and that in the middle to lower esophagus are 2.3 cm/s and 3.7 cm/s, respectively. In our study, the progression speed in patients with preserved peristalsis was in this range. However, the progression speed in patients with completely disrupted peristalsis tended to be slower.

In our study, the passage of peristalsis through the tumor correlated well with the patients' clinical symptoms. Most patients with completely interrupted peristalsis had severe dysphagia, whereas patients with partially interrupted and preserved peristalsis remained asymptomatic or had only minimal dysphagia. Preservation of esophageal motility may depend on the extent of the circumference involved by tumor. In the literature, difficulty in swallowing is not described until the esophagus is narrowed to one-third or one-half its normal circumference.¹ Probably because partial interruption of esophageal peristalsis does not necessarily result in dysphagia, most patients with esophageal tumor can remain asymptomatic until the tumor becomes far advanced.

Although the number of patients in our series is limited, interruption of esophageal peristalsis in these patients may be induced by impaired muscle function caused by invasion of advanced esophageal cancer. The muscular involvement, an important prognostic factor, cannot be evaluated on cross-sectional images, including CT or MRI, and is usually evaluated by endoscopic ultrasonography (EUS), although its accuracy is not satisfactory.^{7,8} Cine MR may become a useful modality for evaluating muscular involvement by esophageal cancers.

Our data in normal volunteers showed that cine MR imaging without contrast enhancement did not provide sufficient image quality to evaluate the esophagus. Because the image contrast of trueFISP sequences depends on T_2/T_1 properties, good contrast between the esophageal wall and adjacent structures may be enhanced by contrast materials.^{9,10}

The current study has several limitations. First, MR study protocols were not optimized. We did not compare the MR protocols with different scan parameters by altering slice thickness, temporal resolution, or other parameters. Technical improvement may allow better visualization of esophageal peristalsis. Second, because the course of the esophagus is usually curved, a mature technologist may be required to set the plane along the long axis of the esophagus. In patients with cancer at the esophageal-cardiac junction, cine MR imaging may be difficult because the plane along the esophageal course cannot be obtained. Third, the gold standard for tumor stages was not uniform in our series, and the number of patients was limited. Moreover, Stage T₂ cancers were absent in our study population. To demonstrate the utility of cine MR imaging in evaluating muscle movement,

further study will be required with a larger number of surgically confirmed cases. Finally, our study did not include normal volunteers, and the data from cine MR imaging in patients with esophageal tumors were not compared with those in normal subjects. However, we believe the interruption of peristalsis to be a distinctively pathologic condition that must not be seen in healthy subjects without digestive problems.

In conclusion, cine MR imaging utilizing SSFP sequencing allows visualization of esophageal peristalsis in relation to esophageal tumor. Complete interruption of peristalsis causes dysphagia, whereas partial interruption of and preserved peristalsis usually do not cause digestive problems. Interruption of peristalsis may indicate impaired muscle function caused by invasion of advanced esophageal cancers.

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