Esophagus imaging with intraluminal RF coil for integrated MR-endoscope system

Y. Matsuoka[1], H. Yoshinaka[1], S. Aizawa[2], M. Matsumoto[2], Y. Morita[1], H. Kutsumi[1], E. Kumamoto[3], K. Kuroda[4,5], and T. Azuma[1]

[1]Graduate School of Medicine, Kobe University, Kobe, Hyogo, Japan, [2]Graduate School of Engineering, Kobe University, Kobe, Hyogo, Japan, [3]Information Science and Technology Center, Kobe University, Kobe, Hyogo, Japan, [4]Medical Device Development Center, Foundation for Biomedical Research and Innovation, Kobe, Hyogo, Japan, [5]School of Information Science and Technology, Tokai Univesity, Hiratsuka, Japan

Introduction

An endoscope is an invaluable instrument for examining visually inside body and minimally invasive surgery. The endoscope shows images of interior surfaces of organ or tissue and has a difficulty in examining internal tissue information even if the techniques of narrow band imaging (NBI) and optical coherence tomography (OCT) are used. The information under the tissue surface is very important for precise diagnosis and pre-operative planning. MRI has some advantages of high soft-tissue contrast, arbitrary slice orientation, no ionizing radiation and so on compared with endoscopic ultrasound (EUS) and X-ray CT. To assist endoscopy and endoscopic surgery safely and precisely, an integrated MR-endoscope system has been offered, which is able to perform MR imaging during endoscopy and fuse the images obtained by both of the modalities. To provide the new feature in this system, the intraluminal RF coil to image the esophagus was developed and the feasibility of esophagus imaging by that coil was examined with an animal tissue in vitro using a tracking system to detect the location and orientation of the RF coil in MRI.

Materials and Methods

The receive-only intraluminal RF coil for imaging of esophagus was designed as a four-loop saddle structure 40 mm in length with a copper line 0.2 mm in width and 0.035 mm in thickness on a polyimide substrate 0.025 mm in thickness. The coil was embedded in a vinyl tube about 14 mm in inner diameter and 17 mm in outer diameter. The resonant frequency and impedance of the coil should be adjusted to an MR scanner (Signa EXCITE Twin Speed 1.5T ver.11, GE Healthcare, USA). The resonant frequency and impedance of the coil usually change when the loading circumstance to the coil changes [1, 2]. Therefore, the coil was tuned and matched to the values including prospective shift of the resonant frequency and impedance when the coil was inserted into the esophagus. The coil circuit for tuning, matching and active decoupling was composed of non-magnetic capacitors (ATC700 A, American Technical Ceramics Corp., USA) and PIN diode (UM9995, Microsemi Corp., USA). We used a tracking system (EndoScout, Robin Medical Inc., USA) to detect the location and orientation of the coil in MRI and define the MR scan range. A tracking sensor of catheter type was attached near the coil. The coil including the tracking sensor was inserted into the excised porcine esophagus which was preserved at about 4 °C with physiological saline over 11 days before the experiment, and then those were immersed in the physiological saline to conduct MR imaging. At first, the MR scan range was decided using the tracking results, and next the MR imaging with wide field of view (FOV) was performed. Using obtained images the scanning position for the cross-sectional imaging with high spatial resolution was set. The sequences for the cross-sectional imaging were as follows: fast spin echo (FSE) with TR, 300 ms; TE, 14.7 ms; ET, 4; readout bandwidth, 15.6 kHz; FOV, 4×4 cm; slice thickness, 3 mm; acquisition matrix, 256 × 128; signal acquisition, 2 as T1-weighted image and TR, 3000 ms; TE, 103.0 ms; ET, 16 as T2-weighted image.

Results

The changes of the resonant frequency, impedance and quality (Q) factor of the coil between in the esophagus and at the load of 2% agar gel were about 1.1 MHz, 15 ohm and 19, respectively. The perfect tuning and matching of the coil in the esophagus were not achieved, however the Q factor in the esophagus was about 95. The slice positions for MR imaging were suitably determined using the tracking results. The in-plane resolution of 0.156 × 0.156 mm was achieved in the cross-sectional image (Figure 1). Mucosa, submucosa and muscularis in the esophageal wall could be visualized in T1-weighted image. In addition, adventitia could be distinguished in T2-weighted image. The tissue used in this study was assumed to be deteriorated because it was preserved with physiological saline for long periods. Therefore, the appearance of each layer in the esophagus in T1- and T2-weighted images, especially the region of mucosa, might be different from that of normal tissue. The signal to noise ratios (SNRs) of mucosa and muscularis were about 61 and 30 in T1-weighted image, and about 71 and 48 in T2-weighted image. The contrast to noise ratio (CNR) between mucosa and muscularis was about 31 and 25 in T1- and T2-weighted image, respectively.

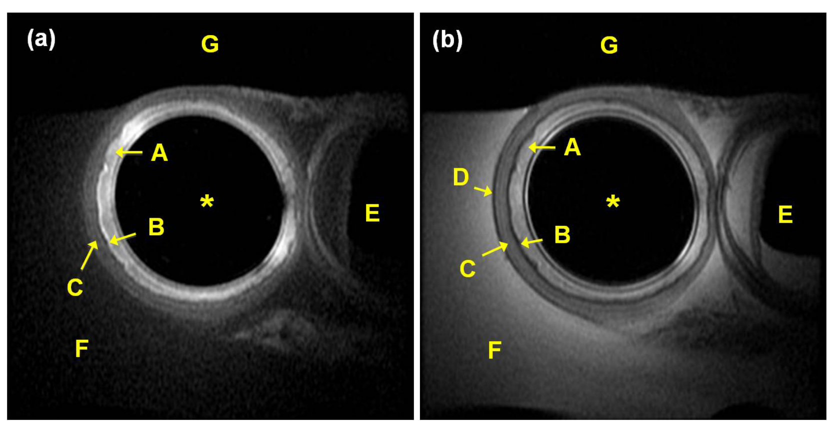

Figure 1. Cross-sectional MR images of excised porcine esophagus. (a) T1-weighted image, (b) T2-weighted image. The spatial resolution of these images are 0.156 × 0.156 × 3 mm. * indicates intraluminal RF coil. **A**, **B**, **C** and **D** might correspond to mucosa, submucosa, muscularis and adventitia in esophageal wall. **E** shows trachea and the high signal intensity in this tract could be physiological saline flowed in there. **F** and **G** indicate the physiological saline and air. The thickness of esophageal wall measured in these images was within about 4 mm.

Conclusion

The feasibility of imaging the esophagus using the intraluminal RF coil was verified by an in vitro experiment. The ability of depicting the anatomical structure in esophagus would help to assist precise diagnosis and surgeries by endoscope. The tracking of the location and orientation of the coil would help to determine the scanning position and also be applicable to the strategy for image fusion of MR images and endoscope view in the integrated MR-endoscope system. The method for precise tuning and matching of the coil inside body should be required to obtain the high SNR images, and the imaging strategy of the esophagus to reduce an artifact from cardiac beating and blood flow should be optimized as the next step.

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References

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