Eur Radiol (2014) 24:2137–2145
DOI 10.1007/s00330-014-3267-x

GASTROINTESTINAL

MRI patterns of Nissen fundoplication: normal appearance and mechanisms of failure

Christiane Kulinna-Cosentini · Wolfgang Schima · Ahmed Ba-Ssalamah · Enrico P. Cosentini

Received: 10 December 2013 / Revised: 18 May 2014 / Accepted: 27 May 2014 / Published online: 26 June 2014
© European Society of Radiology 2014

Abstract

Purpose The purpose of the study was to assess the role of MR fluoroscopy in the evaluation of post-surgical conditions of Nissen fundoplication due to gastro-oesophageal reflux disease (GERD).

Methods A total of 29 patients (21 patients with recurrent/persistent symptoms and eight asymptomatic patients as the control group) underwent MRI of the oesophagus and gastro-oesophageal junction (GEJ) at 1.5 T. Bolus transit of a buttermilk-spiked gadolinium mixture was evaluated with T2-weighted half-Fourier acquisition single-shot turbo spin-echo (HASTE) and dynamic gradient echo sequences (B-FFE) in three planes. The results of MRI were compared with intraoperative findings, or, if the patients were treated conservatively, with endoscopy, manometry, pH-metry and barium swallow.

Results MRI was able to determine the position of fundoplication wrap in 27/29 cases (93 % overall accuracy) and to correctly identify 4/6 malpositions (67 %), as well as all four wrap disruptions. All five stenoses in the GEJ were identified and could be confirmed intraoperatively or during dilatation. MRI correctly visualized three cases with motility disorders, which were manometrically confirmed as secondary achalasia. Three patients showed signs of recurrent reflux without anatomical failure.

Conclusion MRI is a promising diagnostic method to evaluate morphologic integrity of Nissen fundoplication and functional disorders after surgery.

Key points

- *MRI offers simultaneous morphological and functional imaging in one diagnostic method.*
- *MR fluoroscopy offers the possibility to identify the wrap position.*
- *MRI enables a non-invasive diagnosis, providing detailed information for the surgeon.*

Keywords Magnetic resonance imaging · Esophagogastric junction · Swallowing · Fundoplication · Nissen operation

Introduction

Laparoscopic antireflux surgery (LARS) has become the most accepted form of surgical therapy for gastroesophageal reflux since its introduction in 1991 [1]. Nissen fundoplication is the most commonly applied surgical procedure, which involves wrapping the fundus around the lower oesophageal sphincter (LES) in a 360° manner [2]. Subsequently, the basal LES pressure increases and episodes of transient LES relaxations can be decreased [3]. Follow-up studies report good clinical outcomes in approximately 90 % of patients at 5 years after surgery [4, 5], but new or recurrent postoperative complaints may occur in up to 2–17 % [6] of patients. In the early postoperative phase, symptoms such as mild dysphagia, bloating or mild heartburn are not uncommon, but should resolve within 6 weeks. In the later phase, heartburn and regurgitation are the most common presenting symptoms,

Electronic supplementary material The online version of this article (doi:10.1007/s00330-014-3267-x) contains supplementary material, which is available to authorized users.

C. Kulinna-Cosentini (✉) · A. Ba-Ssalamah
Department of Biomedical Imaging and Image-guided Therapy, Medical University of Vienna, Waehringer Guertel 18-20, 1090 Vienna, Austria
e-mail: christiane.kulinna-cosentini@meduniwien.ac.at

W. Schima
Department of Radiology, Krankenhaus Göttlicher Heiland, Krankenhaus der Barmherzigen Schwestern Wien und Sankt Josef Krankenhaus, Vienna, Austria

E. P. Cosentini
Department of Surgery, Medical University of Vienna, Vienna, Austria

among persistent dysphagia, weight loss and gas bloating syndrome [7, 8].

In patients with recurrent or persistent symptoms after fundoplication, the underlying mechanisms are not completely understood, but different aspects like oesophageal motor dysfunction as well as tightness of the fundoplication wrap or failed wrap position may be responsible for postoperative dysphagia.

A wide range of diagnostic modalities are used, such as endoscopy, 24-h pH monitoring, manometry and barium swallow, which all cover only partial aspects of potential postoperative failure. However, these techniques are inaccurate in up to 40 % of patients [9] in clarifying the cause of postoperative dysphagia, when compared to intraoperative findings during re-operation. Because this patient group often is of young age, a growing effort has been made to develop functional and morphologic imaging without ionizing radiation. At present, MR fluoroscopy has been effectively used in oropharyngeal imaging [10, 11] and for the assessment of oesophageal motility disorders, GERD [12–14], as well as for post-surgery patients after narrow gastric tube reconstruction in oesophagectomy [15]. The aim of our work was to define the morphologic and functional patterns of normality and the appearance of failure after Nissen fundoplication on using MR fluoroscopy.

Methods

Patients

Ethical approval for the prospective study was obtained by the institutional review board and informed consent was obtained for each patient. Between May 2008 and September 2012, 21 patients with persistent, recurrent or new symptoms (11 male, 10 female; mean age, 56 years; range, 38–77 years) were enrolled in the study, as well as eight patients (seven male, one female; mean age, 46 years; range, 34–71 years) without symptoms as a control group. All patients had undergone LARS with Nissen fundoplication. The symptoms recurred at 3–35 months after operation and had existed for 4–35 months at the time of MRI. The leading symptoms included heartburn, regurgitation and dysphagia.

Patients with symptoms were examined by endoscopy (n=19) for wrap location/disruption and tightness of the wrap, by barium swallow (n=12) for wrap dislocation and motility disorder, by pH-metry (n=16) for reflux on the basis of a pathological DeMeester score >14.72, by manometry (n=16) for motility disorder on the basis of pathological pressure and incomplete relaxation, and finally, by MR fluoroscopy (n=21). MR fluoroscopy was performed blinded to the examination results of the other examinations. The asymptomatic patients underwent only MRI and endoscopy as control examinations at 12 months after surgery. Results of MR fluoroscopy were ultimately compared to surgical results (n=15).

Patients with general contraindications to MR examinations, as well as patients younger than 18 years of age, were excluded from the study.

Surgical technique

Three experienced surgeons performed all operations. The surgical technique included the reduction of the hiatal hernia, when present, with primary closure of the diaphragmatic crura with one or two sutures. Dissection of two to four short gastric vessels, to mobilize the gastric fundus and obtain a floppy and well-shaped fundoplication, was routinely performed. The fundus was wrapped posteriorly around the distal oesophagus, as well as the lower oesophageal sphincter, and sutured anteriorly, creating a 360° (Nissen) wrap with three nonabsorbable stitches. The two distally placed sutures included the anterior oesophageal wall. Published failure rates of laparoscopic Nissen fundoplication are 2–17 %, depending on the definition of failure and experience of the surgeons [16]. Five main categories of failure patterns after Nissen Fundoplication can be described:

1. The *slipped or misplaced wrap*, often seen as an intrathoracic migration of the wrap. Slipping of the wrap occurred when the hiatal sutures or the suture of the wrap with the anterior oesophageal wall was disrupted [17]. Some authors also describe this phenomenon as recurrent hernia [18, 19].
2. The *disrupted wrap* mostly results in recurrent reflux and is caused by disruption of the anterior wrap sutures [17].
3. The so-called *slipped Nissen* or telescope phenomenon means that a part of the stomach is slipped through the fundus wrap [17].
4. Surgical overcorrection means a *too tight or too long wrap* as well as *too tight crural sutures* [17, 20, 21] mostly resulting in persistent dysphagia.
5. So-called *secondary achalasia* or postoperative motility disorder: it is usually caused by an inappropriate surgical selection of patients with profound preoperative oesophageal hypomotility [22].

MR fluoroscopy

Examinations were performed in the supine position on a 1.5-Tesla unit (Intera, Philips, Best, Netherlands) with a phased-array body coil placed upon the chest. The following image protocol was performed to locate the oesophagus and its course, then to locate the gastro-oesophageal junction (GEJ)

with the exact position of the wrap and lastly to evaluate the functionality of oesophageal motility:

1. Position of the oesophagus: After a reference examination, a coronal T2-weighted half-Fourier acquired single-shot turbo spin-echo (HASTE) sequence was obtained to depict the complete course of the oesophagus, anatomic landmarks like upper oesophageal sphincter region and GEJ.
2. Position of fundoplication wrap and recurrent hernia: After the sagittal T2w HASTE sequence, a strictly axial T2w HASTE sequence was performed to evaluate the fundoplication wrap and a recurrent hiatal hernia. The coronal sequence was bent to the course of the lower oesophagus.
3. Dynamic evaluation of bolus transit: To determine the optimum slice angle, a sagittal oblique B-FFE sequence was centred on the lower oesophagus, as seen on the coronal T2w HASTE sequence. The sagittal oblique B-FFE sequence was performed as a pulse sequence with three contiguous slices for better coverage of the entire course of the oesophagus and to compensate if the oesophagus slipped out of the imaging plane due to breathing. Coronal oblique T2w HASTE images were also obtained. Finally, an axial B-FFE pulse sequence was obtained at the level of the GEJ.

The pulse sequence was repeated if delay of oesophageal emptying was observed in the first dynamic sequence. The sequence parameters are listed in Table 1.

A buttermilk–gadolinium mixture (gadodiamide, GE Healthcare, Oslo, Norway) comprising 240 ml buttermilk and 6 ml of gadodiamide (dilution of 40:1) was poured into a cup with a long plastic tube and was placed near the patient's head in the MR gantry, so that the other end of the plastic tube could be placed into the volunteer's mouth. To avoid possible complications, i.e. aspiration, the ability of volunteers to swallow in the supine position was tested outside the magnet before the examination.

Table 1 MR sequence parameter

Parameter	HASTE	B-FFE
Repetition time (ms)	1,800	2.9
Echo time (ms)	100	1.5
Flip angle (°)	150	60
Acquisition matrix	256×256	256×256
Field of view (mm)	350×350	375×375
Slice thickness (mm)	5	15
Intersection gap (mm)	–	0.4
Acquisition time (s/image)	1	1
Acquisition cycle (s)	–	60
Slice orientation	1. coronal 2. sagittal 3. axial	1. sagittal oblique 2. coronal oblique 3. axial

Patients were instructed to take a bolus of the buttermilk–gadolinium mixture and to swallow it in a single gulp, then open their mouth after each swallow to prevent repetitive swallowing. If coverage of the oesophagus was inadequate, the pulse sequence was repeated at a slightly different angulation.

After the transit of three single boluses, patients were assessed for the presence of spontaneous reflux, followed by a Valsalva manoeuvre, examined in all three planes.

Image analysis

MR images were analysed by two radiologists in cine-mode and in a frame-by-frame analysis, in consensus, for the morphology of the GEJ and functional disorders.

Pathological findings were classified into two subgroups:

A. Morphologic or structural abnormalities
B. Functional abnormalities/motility disorders

The images were analysed to determine the presence or absence of abnormalities as follows:

A. Morphologic or structural abnormalities:

1. *Normal position*: Images were rated presenting normal appearance if the fundoplication wrap was seen under the diaphragm with a ring-like "pseudotumour" of the fundoplication, as well as a defined smooth defect in the fundus. Contrast medium passed through the centre of the pseudotumour. In patients without pathological findings, no hernia above the wrap and no reflux was seen under a Valsalva manoeuvre or spontaneously.
2. *A slipped wrap* is defined by an intrathoracic migration of the wrap or recurrent hernia. On MRI, the typical ring-like pseudotumour cannot be seen below the diaphragm, but sometimes can be seen in the thorax.
3. In cases of *wrap disruption* the typical pseudotumour-like ring cannot be seen. A special type of this failure is the partly ruptured wrap, which appeared as an "open semi-ring".
4. Images are rated as *slipped Nissen* or telescope phenomenon when a part of the stomach is slipped through the fundus wrap.
5. *Too tight wrap or too tight crural sutures*: On MR fluoroscopy, normal oesophageal peristalsis and bolus transit time up to the wrap region could be seen in patients with narrowing. In our experience a too tight wrap produced a long segment of stenosis of about 2–3 cm, whereas too tight crural sutures resulted in a short segment of stenosis of less than 1 cm caused by too tight crural sutures in our population.

For group B (motility disorders) the subjective assessment was categorized as follows:

1. Delayed bolus transit: bolus transit time of a 5-ml liquid contrast medium bolus, which was swallowed in a single gulp, took more than 20 s from upper to lower oesophageal sphincter [22].
2. Non-propulsive contractions.

Results

MR fluoroscopy was well tolerated by all patients and no complications occurred during MRI. The average examination time, including patient preparation, was 29±5 min. Anatomic landmarks, such as the upper oesophageal sphincter region, the oesophagus and the GEJ, could be identified in all patients (100 %). Visualization of the bolus transit through the entire oesophagus between the cricopharyngeal sphincter and the stomach was completely visualized in all patients. Each abnormality of the Nissen fundoplication in our series was affiliated with particular imaging features in MRI (Table 2).

Fifteen patients underwent re-operation/bougienage. Of these 15 patients, six had slipped wraps, four showed wrap disruption and two with too tight a wrap were operated on. The three patients with too tight crural sutures underwent bougienage, and the four reflux patients showing no anatomical problem were treated conservatively with proton pump inhibitors. If the patients were treated conservatively or by bougienage, the results of manometry, pH-metry, endoscopy and barium swallow were used as the standard of reference.

Table 2 MR fluoroscopic hallmarks of complications of the Nissen fundoplication

Complication	MR findings
Slipped wrap	The typical ring-like pseudotumour is missed below diaphragm, sometimes it can be seen beside the oesophagus intrathoracically as a small ring
Wrap disruption	The pseudotumour-like ring cannot be seen anymore
	An “open semi-ring” is to be interpreted as a part-rupture of the wrap
Telescope phenomenon	Images not obtained
Crural sutures too tight	Too tight wrap: a long stenosis of about 2–3 cm; too tight crural sutures: a short stenosis of less then 1 cm
Secondary achalasia	Bolus transit time >20 s, dilated oesophagus, non-propulsive contractions
Recurrent reflux	Contrast medium passes backwards into the oesophagus, mostly in patients with wrap disruption

Normal pattern

In all patients without postoperative symptoms (n=8), normal primary peristalsis, with a normal oesophageal bolus transit time, as well as a wrap position projected entirely below the diaphragm (Fig. 1) could be observed.

Slipped wrap

In all patients with a slipped wrap (n=6) (Fig. 2), this was confirmed during re-operation. Four of them (67 %) could be correctly identified on MRI, whereas two cases were misdiagnosed as wrap disruption. Two patients (33 %) were correctly diagnosed by endoscopy, and three patients were diagnosed by barium swallow. Three patients did not undergo a barium swallow.

Wrap disruption

All wrap disruptions (n=4) were confirmed surgically. MRI allowed correct diagnosis in all four patients (Fig. 3), including one patient with a partial rupture (Fig. 4).

No patients showed wrap disruption on endoscopy, two patients showed wrap disruption on barium swallow, one barium swallow was not diagnostic and one patient did not underwent barium swallow.

Crural sutures or wrap too tight

Five patients showed stenoses in the region of the GEJ (Fig. 5). Three were caused by too tight crural sutures, which underwent bougienage. The two stenosis which were caused by too tight wraps underwent re-operation.

All five stenosis could be detected by MR fluoroscopy, whereas only three stenoses could be seen with endoscopy, and only two stenoses with barium swallow. Two cases were misdiagnosed by endoscopy, as well as one case during the barium swallow. In one patient, a barium swallow was not performed.

Motility disorder

Three patients with manometrically diagnosed motility disorders also demonstrated signs of motility disorders on MR fluoroscopy (Fig. 6), with delayed bolus transit time and lack of propulsive peristalsis. Two patients with stenosis in the GEJ also showed signs of motility disorders, as well as three patients with a slipped wrap.

Recurrent reflux

An increased DeMeester score (>14.72) in pH-metry [13] was diagnostic for reflux in 10 of 16 patients

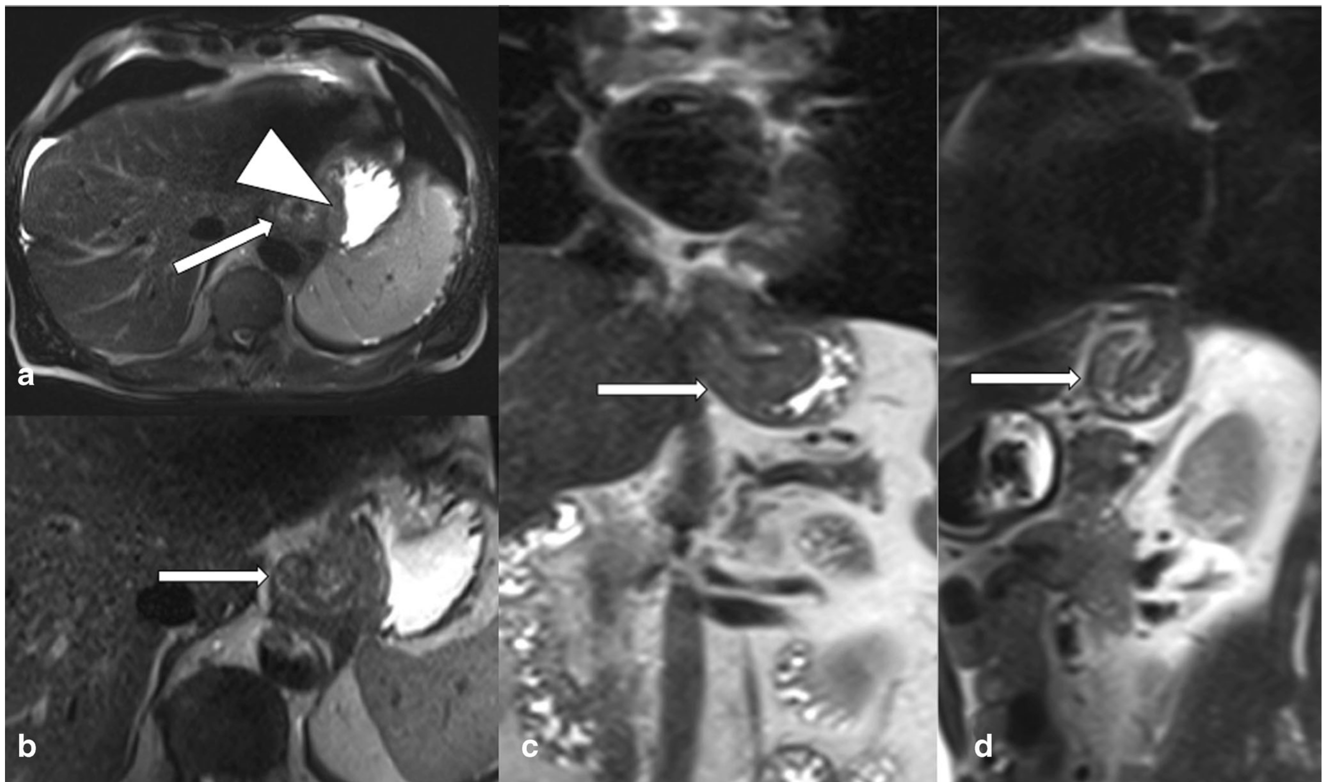

Fig. 1 Normal postoperative appearance after Nissen fundoplication on MRI. **a**, **b** A ring-like pseudotumour (*arrow*) of the fundoplication, and a well-defined smooth defect in the fundus (*arrowhead*), acquired in the axial plane. **c** An additional coronal view shows the correct position of the wrap under the diaphragm. **d** Contrast medium passes through the centre of the pseudotumour (*arrow*) in the sagittal view

(63 %). Of these 10 patients (two with slipped wrap, three with wrap disruption, one with stenosis in wrap, one with secondary achalasia and three patients without an anatomical abnormality), reflux on MRI could be assessed in only five patients (50 %).

Discussion

This study analysed the use of dynamic MRI as a diagnostic modality for the evaluation of the anatomy and function of the GEJ after laparoscopic antireflux surgery that included Nissen

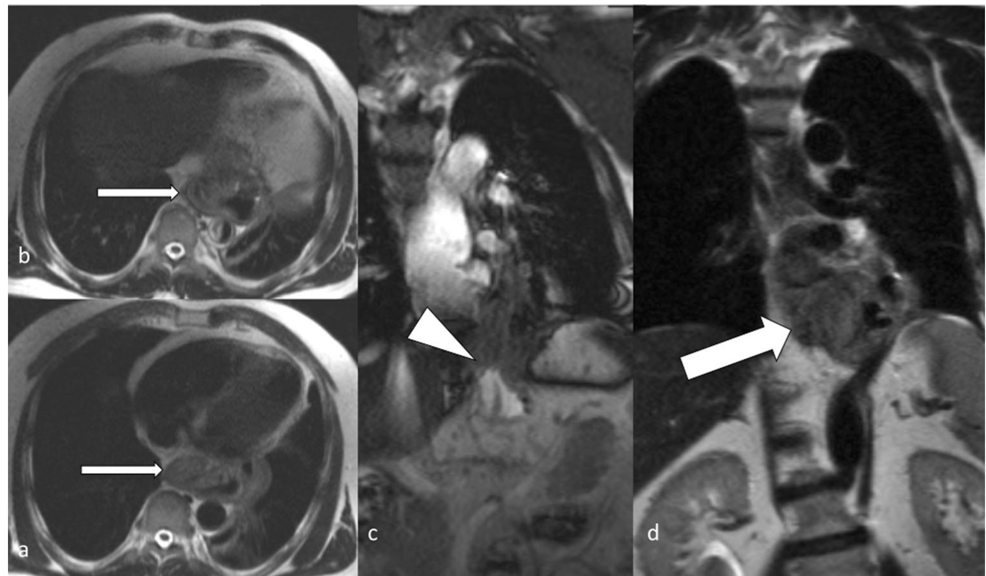

Fig. 2 Slipped wrap. **a**, **b** T2w HASTE sequences in the axial view were performed to demonstrate the integrity of the wrap (*arrow*). **c**, **d** MR fluoroscopy in the coronal view shows that the entire wrap (*arrow*) lies above the oesophageal hiatus (*arrowhead*) in a patient with postprandial chest fullness

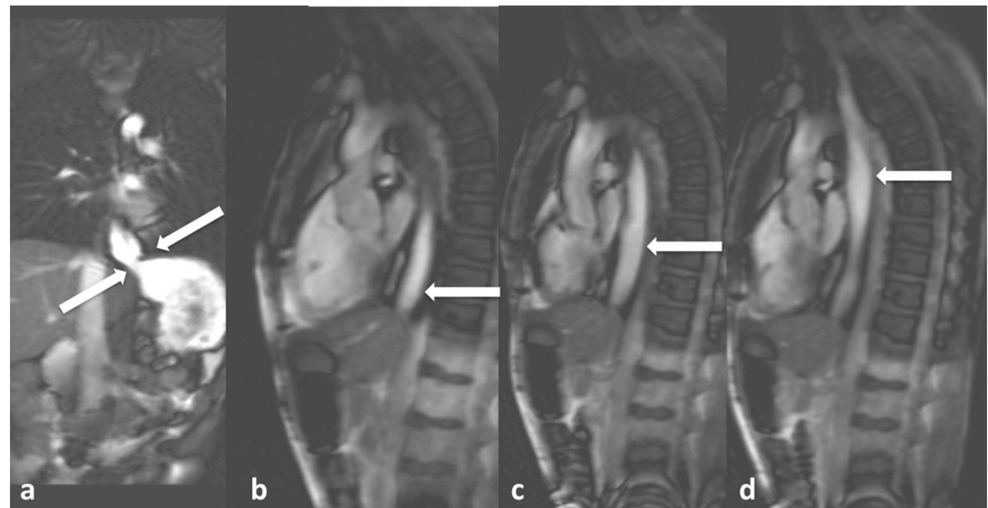

Fig. 3 Complete wrap disruption obtained in a patient with symptoms of recurrent reflux. **a** The typical pseudotumour is missed on the coronal (*arrows*) view. **b**–**d** On the dynamic sagittal view reflux up to the proximal part of the oesophagus is identified (*arrows*)

fundoplication. Our data demonstrate that MRI is feasible for the visualization of the normal pattern of hiatal anatomy, as well as for the demonstration of the pathologic pattern of the integrity of a fundoplication wrap and its relationship to the diaphragm. Because of the simultaneous view MRI offers of the oesophagus and the hiatal region and its surrounding structures, various mechanisms of postoperative failure can be detected. Owing to an examination time of approximately 30 min, dynamic MRI can easily be performed in routine clinical practice.

With the introduction of ultrafast MR sequences, which have increased temporal resolution to the sub-second level, dynamic MR fluoroscopy has become a reality for the assessment of morphologic and functional imaging of the oesophagus [10–14]. However, studies evaluating MR fluoroscopy, and evaluating symptomatic patients after antireflux surgery, have not been published as yet. Dynamic MR fluoroscopy has the advantage over barium studies in visualizing not only luminal structures, but the structural details of the oesophagus and stomach itself as well as the surrounding structures. So malpositions or disruptions of fundoplication wraps as well as anatomical abnormalities in the hiatal region and motility problems can be detected with this method.

The use of a short MRI protocol, developed through this study of normal and pathological patterns, offers the opportunity to perform examinations within normal clinical routine.

Starting with a single-shot (HASTE) sequence allows a good overview of the postoperative anatomic situation of the GEJ and the wrap situation. It also serves to position the dynamic, double-angulated B-FFE sequences. This sequence allows accurate depiction of the whole oesophagus, enabling measurement of the bolus transit time and demonstrating the presence of peristalsis for the evaluation of possible motility disorders and the function of the LES.

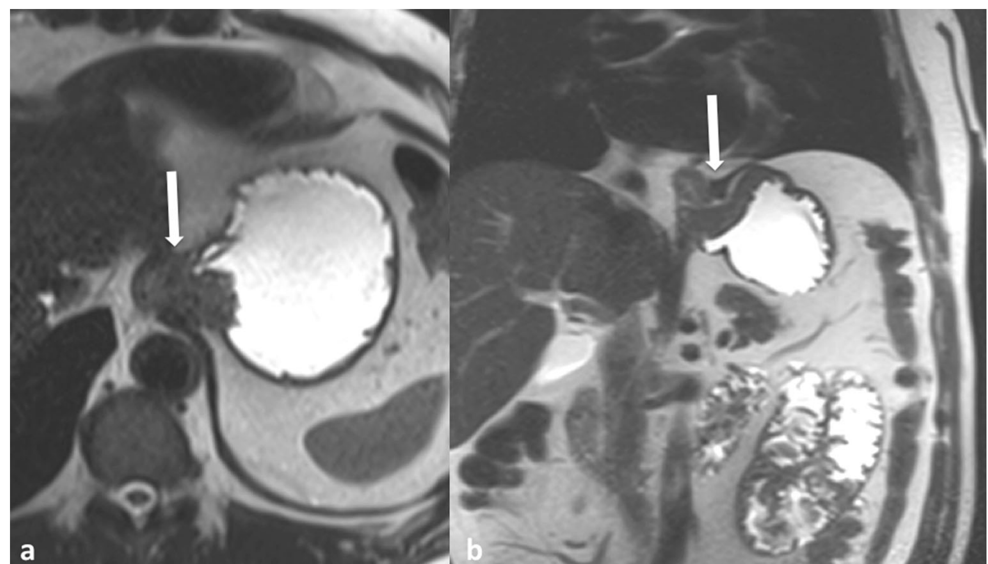

Fig. 4 Incomplete wrap disruption. **a**, **b** If an open “semi-ring” (*arrow*) is found on axial and on coronal MR images, an incomplete wrap disruption should be diagnosed

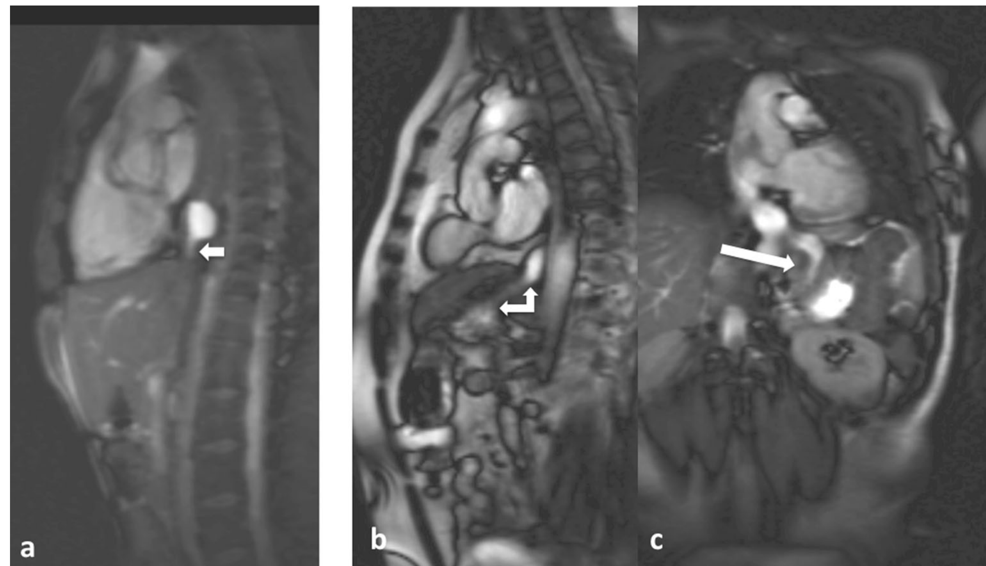

Fig. 5 Stenosis at the gastro-oesophageal junction. **a** If the stenosis measures less than 1 cm in length on the sagittal view, this short stenosis (*short arrow*) strongly suggests too tight crural sutures as the cause of dysphagia. **b**, **c** A long stenosis of 2–3 cm (*long arrows*) on sagittal and coronal images is primarily caused by a too tight wrap

In previous studies different sequences have been examined for cine MRI of the oesophagus: a maximal frame rate of five images per second has been obtained by fast low angle shot (FLASH) and turbo-FLASH sequences, but provided poor contrast resolution and limited temporal resolution [14]. Echo planar imaging suffers from high temporal resolution, but is encumbered by poor spatial resolution and many motion artefacts [23]. In a recent study, the SSFP technique, a true fast imaging sequence with steady precession (TrueFISP, Siemens, Erlangen, Germany), was successfully used for swallowing MRI exams [11]. Excellent temporal resolution (4.5–13 frames/s), owing to very short TR and TE, and adequate spatial resolution have been acquired by this sequence.

In the present study, the frame rate of the SSFP pulse sequence (B-FFE; Philips) was limited to one image per second, but the number of contiguous slices was increased to three and the spatial resolution was increased by using a matrix of 256×256. This technique provided clear images of the oesophageal phase and GEJ, which was also shown in a previous study in healthy volunteers [24]

The most helpful view for depicting the entire oesophagus is the sagittal view, because, in the sagittal plane, the oesophagus has a nearly straight course. Thus, this view is predominantly used to assess the bolus transit time and the peristalsis. In addition to the sagittal view, the coronal oblique view can be very helpful in visualizing reflux and evaluating the hiatal region precisely. The position of the wrap and the lumen (which is wrapped), as well as the length of the wrap and the condition of the crural sutures, can therefore be determined very well in two planes. To examine the integrity of the wrap and to evaluate a recurrent hiatal hernia, the axial view is predominantly used.

MR fluoroscopy is performed in the supine position, although this is not the physiological position for swallowing.

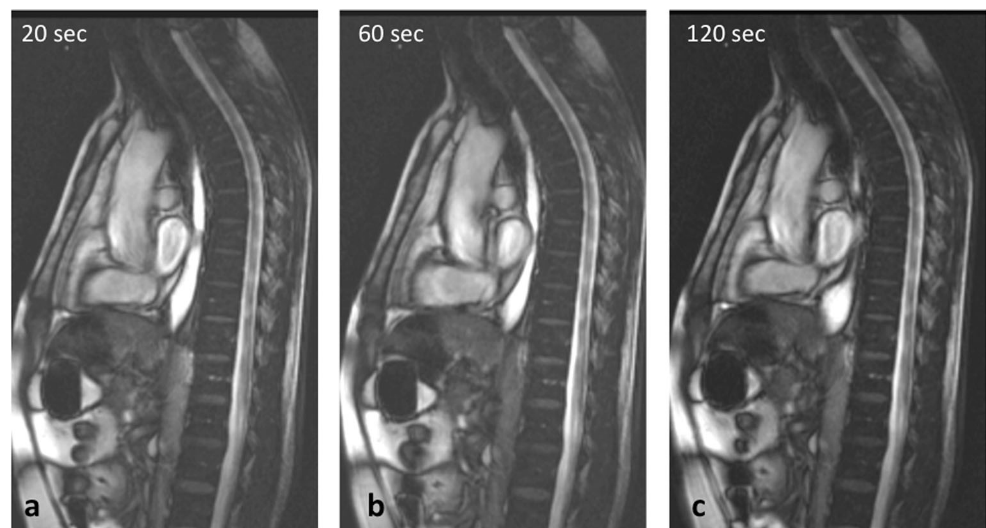

Fig. 6 Advanced motility disorder. **a**–**c** Sagittal MR images acquired 20, 60 and 120 s after bolus administration, showing distention of the oesophagus and tapered narrowing of the gastro-oesophageal junction. Clearing of the oesophagus is delayed

However, the presence of reflux can often be visualized in the supine position [14]. Moreover, other examination techniques used for postoperative assessment, such as endoscopy, are also performed in the recumbent position.

Endoscopy, manometry, pH-metry and barium swallow are the main evaluation tools if failure of antireflux surgery is suspected. Frequently, these methods are used in combination, because they are unable to diagnose the mechanism of failure individually and comprehensively.

Although a high percentage of barium swallow studies are abnormal in patients with postoperative complaints like wrap migration, tapered narrowing of GEJ or GE reflux [25], these examinations accurately predict intraoperative findings in only 62 % of patients [6]. In our study, good results could be obtained for the diagnosis of wrap disruption and slipped wrap with barium swallow, whereas only 40 % of the cases reported in the literature have been correctly diagnosed [6]. Indeed, two of five patients with stenosis in the GEJ could be detected with barium swallow. One explanation might be misinterpretation as a "normal postoperative narrowing" after fundoplication. It is important to know that barium swallow—only at the time of symptoms—can lead to the correct diagnosis. Immediate postoperative barium studies following LARS are of little value in determining important postoperative problems [26].

Endoscopy is one of the main pillars of the routine workup for failed fundoplication, but no clear guidelines for endoscopic terminology exist [27]. The results are strongly dependent on the kind of procedure, intra-abdominal pressure, inspiration or expiration and the amount of insufflated air [18]. In our study, endoscopy failed to diagnose the location of the wrap or even its disruption: Of the nine cases, five were misdiagnosed as recurrent hiatal hernia or newly acquired para-oesophageal hernia, and, in four cases, there was a false diagnosis of reflux oesophagitis. In the literature, endoscopy also shows a poor objective correlation with patient-reported symptoms, especially if the recurrent symptom is heartburn [28]. In a study by Lord et al. [28], no endoscopic abnormalities could be found in 62 % of all symptomatic patients (39/63 patients).

While MRI showed poor results in diagnosing reflux in our study, with 56 % (five of nine patients), 24-h pH-metry still seems to be essential for identifying patients with persistent or recurrent oesophageal acid exposure, as was the case in nine of 14 patients (64 %) with a pathological DeMeester score. But, this method offers little information regarding the specific cause of failure [3–5].

Manometry can locate only the level of the LES, measure sphincter resting pressure and its relaxation, and determine the presence of motility disorders [29–32], especially a secondary achalasia [33], whereas MR fluoroscopy seems to be especially suited to clarify the situation concerning wrap dislocation and disruption, as well as functionality of oesophageal peristalsis [13, 14].

The small patient number is one of the main limitations of our preliminary paper. Further studies, with a larger number of patients, are necessary to determine the value of MR fluoroscopy for this indication. Another problem is that temporal resolution of MR fluoroscopy is not yet comparable to the standards obtainable with barium swallow (25–30 frame/s). To solve this problem and to get a true real-time visualization especially of oesophageal motility, the lowest values of flip angle, TR and TE should be used [34].

A few studies have demonstrated that symptoms are an unpredictable indicator of postoperative complications [35], and that many "anatomic" failures may be seen in asymptomatic patients [36]. Therefore, an exact reproducible diagnostic procedure is mandatory. MR fluoroscopy is quite advantageous in identifying anatomic or functional problems resulting after failed fundoplication, and provides information to the surgeon for a tailored subsequent operative treatment. The greatest advantage is the combination of morphological and functional information within one diagnostic method, as well as a simultaneous view of the oesophagus, the GEJ, the surrounding structures and especially the "wrap situation."

In conclusion, we showed that dynamic MR fluoroscopy is a promising non-invasive method with which to evaluate the anatomy and function of the GEJ after Nissen fundoplication. The various reasons for failure can be confidently visualized with MR fluoroscopy, and morphologic as well as functional imaging features can be described to identify those failures after LARS.

Acknowledgements The scientific guarantor of this publication is Enrico P. Cosentini. The authors of this manuscript declare no relationships with any companies whose products or services may be related to the subject matter of the article. The authors state that this work has not received any funding. One of the authors has significant statistical expertise. No complex statistical methods were necessary for this paper. Institutional review board approval was obtained. Written informed consent was obtained from all subjects (patients) in this study. Methodology: prospective, diagnostic study, performed at one institution.

References

1. Dallemagne B, Weerts JM, Jehaes C, Markiewitz S, Lombard R (1991) Laparoscopic Nissen fundoplication: preliminary report. Surg Laparosc Endosc 1:138–143
2. Broeders JA, Roks DJ, Ali UA et al (2013) Laparoscopic anterior 180-degree versus Nissen fundoplication for gastroesophageal reflux disease. Ann Surg 257:850–859
3. Ireland AC, Holloway RH, Toouli J, Dent J (1993) Mechanisms underlying the antireflux action of fundoplication. Gut 34:303–308
4. Lafullarde T, Watson DI, Jamieson GG, Myers JC, Game PA, Devitt PG (2001) Laparoscopic Nissen fundoplication: five-year results and beyond. Arch Surg 136:180–184
5. Bammer T, Hinder RA, Klaus A, Klingler PJ (2001) Five- to eight-year outcome of the first laparoscopic Nissen fundoplications. J Gastrointest Surg 5:42–48

6. Gopal DV, Chang EY, Kim CY et al (2006) EUS characteristics of Nissen fundoplication: normal appearance and mechanisms of failure. Gastrointest Endosc 63:35–44
7. Yang H, Watson DI, Kelly J, Lally CJ, Myers JC, Jamieson GG (2007) Esophageal manometry and clinical outcome after laparoscopic Nissen fundoplication. J Gastrointest Surg 11:1126–1133
8. Siewert JR, Isolauri J, Feussner H (1989) Reoperation following failed fundoplication. World J Surg 13:791–796
9. Hashemi M, Peters JH, DeMeester TR et al (2000) Laparoscopic repair of large type III hiatal hernia: objective followup reveals high recurrence rate. J Am Coll Surg 190:553–560
10. Hartl DM, Kolb F, Bretagne E, Marandas P, Sigal R (2006) Cine magnetic resonance imaging with single-shot fast spin echo for evaluation of dysphagia and aspiration. Dysphagia 21:156–162
11. Barkhausen J, Goyen M, von Winterfeld F, Lauenstein T, Arweiler-Harbeck D, Debatin JF (2002) Visualization of swallowing using real-time TrueFISP MR fluoroscopy. Eur Rad 12:129–133
12. Curcic J, Fox M, Kaufman E, Forras-Kaufman Z et al (2010) Gastroesophageal junction: structure and function as assessed by using MR imaging. Radiology 257:115–124
13. Panebianco V, Tomei E, Anzidei M et al (2006) Functional MRI in the evaluation of oesophageal motility: feasibility, MRI patterns of normality, and preliminary experience in subjects with motility disorders. Radiol Med 111:881–889
14. Kulinna-Cosentini C, Schima W, Lenglinger J et al (2012) Is there a role for dynamic swallowing MRI in the assessment of gastroesophageal reflux disease and oesophageal motility disorders? Eur Rad 22: 364–370
15. Panebianco V, Francioni F, Anzidei M, Anile M, Rolla M, Pasariello R (2006) Magnetic resonance-fluoroscopy as long-term follow-up examination in patients with narrow gastric tube reconstruction after radical esophagectomy. Eur J Cardiothorac Surg 30:663–668
16. Hunter JG, Smith CD, Branum GD et al (1999) Laparoscopic fundoplication failures: patterns of failure and response to fundoplication revision. Ann Surg 230:595–604
17. Stein HJ, Siewert H, Feussner H (1994) What are the causes of failure of Nissen's operation ? Oeso Knowledge - Interactive Information System. The esophageal mucosa: Nissen fundoplication:1–3
18. Pointner R, Granderath FA (2008) Hiatus hernia and recurrence: the Achilles heel of antireflux surgery? Chirurg 79:974–981
19. Donahue PE, Samelson S, Nyhus LM, Bombeck CT (1985) The floppy Nissen fundoplication. Effective long-term control of pathologic reflux. Arch Surg 120:663–668
20. DeMeester TR, Stein HJ (1992) Minimizing the side effects of antireflux surgery. World J Surg 16:335–336
21. Stein HJ, Feussner H, Siewert JR (1996) Failure of antireflux surgery: causes and management strategies. Am J Surg 171:36–40
22. Tatum RP, Shi G, Manka MA, Brasseur JG, Joehl RJ, Kahrilas PJ (2000) Bolus transit assessed by an esophageal stress test in postfundoplication dysphagia. J Surg Res 9:56–60
23. Manabe T, Kawamitsu H, Higashino T et al (2004) Esophageal magnetic resonance fluoroscopy: optimization of the sequence. J Comput Assist Tomogr 28:697–703
24. Kulinna-Cosentini C, Schima W, Cosentini EP (2007) Dynamic MR imaging of the gastroesophageal junction in healthy volunteers during bolus passage. J Magn Reson Imaging 25:749–754
25. Raeside MC, Madigan D, Myers JC, Devitt PG, Jamieson GG, Thompson SK (2012) Post-fundoplication contrast studies: is there room for improvement? Br J Rad 85:792–799
26. Szwerc MF, Gagne DJ, Wiechmann RJ, Maley RH, Santucci TS, Landreneau RJ (2002) Immediate radiographic assessment following laparoscopic antireflux operations is unnecessary. Surg Endosc 16: 64–66
27. Juhasz A, Sundaram A, Hoshino M, Lee TH, Filipi CJ, Mittal SK (2011) Endoscopic assessment of failed fundoplication: a case for standardization. Surg Endosc 25:3761–3766
28. Lord RV, Kaminski A, Oberg S, Bowrey DJ, Hagen JA, DeMeester SR, Sillin LF, Peters JH, Crookes PF, DeMeester TR (2002) Absence of gastroesophageal reflux disease in a majority of patients taking acid suppression medications after Nissen fundoplication. J Gastrointest Surg 1:3–9
29. Smith CD, McClusky DA, Rajad M, Lederman AB, Hunter JG (2005) When fundoplication fails: redo? Ann Surg 241:861–869
30. Fuchs KH, DeMeester TR, Albertucci M (1987) Specificity and sensitivity of objective diagnosis of gastroesophageal reflux disease. Surgery 102:575–580
31. Hinder RA, Klingler PJ, Perdikis G, Smith SL (1997) Management of the failed antireflux operation. Surg Clin N Am 77:1083–1098
32. Khajanchee YS, O'Rourke R, Cassera MA, Gatta P, Hansen PD, Swanström LL (2002) Laparoscopic reintervention for failed antireflux surgery: subjective and objective outcomes in 176 consecutive patients. Arch Surg 142:791–792
33. Stylopoulos N, Bunker CJ, Rattner DW (2002) Development of achalasia secondary to laparoscopic Nissen fundoplication. J Gastrointest Surg 6:368–376
34. Covotta F, Piretta L, Badiali D et al (2011) Functional magnetic resonance in the evaluation of oesophageal motility disorders. Gastroenterol Res Pract 2011:1–5
35. Galvani C, Fisichella PM, Grorodner MV, Peretta S, Patti MG (2003) Symptoms are a poor indicator of reflux status after fundoplication for gastroesophageal reflux disease: role of esophageal functions tests. Arch Surg 138:514–518
36. Donkervoort SC, Bais JE, Rijnhart-de Jong H, Gooszen HG (2003) Impact of anatomical wrap position on the outcome of Nissen fundoplication. Br J Surg 90:854–859