Magnetic resonance-fluoroscopy as long-term follow-up examination in patients with narrow gastric tube reconstruction after radical esophagectomy

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Received 8 May 2006; received in revised form 4 July 2006; accepted 10 July 2006

Abstract

Objective: To evaluate the functionality and morphology of neo-esophagus in subjects who underwent narrow gastric tube (NGT) reconstruction after total esophagectomy using magnetic resonance (MR)-fluoroscopy with Turbo-FLASH sequences acquired during positive oral contrast agent administration. Methods and materials: Ten patients, who underwent NGT reconstruction after total esophagectomy between 2002 and 2004, were studied using a 1.5 T magnet (Magnetom Avanto: Siemens, Erlangen, Germany, featuring total imaging matrix-TIM® technology), equipped with surface phased-array and integrated spine coils. Imaging protocol included TRUFI and Turbo-FLASH sequences (TR = 600 ms; TE = 1.3 ms; Flip Angle 8°; Thickness 20 mm; FoV 350; Matrix 128x256; N. acquisition 120; TA = 50 s) acquired on sagittal and axial planes to achieve motility evaluation during oral administration of positive contrast agent (yoghurt + Gd-DTPA 0.5 M, 1:100 boluses). Results: Good quality images were obtained in all patients, with adequate lumen contrast and a frame rate of 2.5 frames per second (fps). Three patients had completely re-established motility of NGT; six patients had mild to moderate alterations including raised transit time, reflux and contrast agent stasis; one patient had severe alterations with grossly dilated NGT, severe reflux and stasis. Conclusions: MR-fluoroscopy approach represents a promising radiation-free modality in the evaluation of functionality and morphology of NGT. Further investigation in the evaluation of post-surgery patients is necessary.

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Keywords: Esophagus; Esophagectomy; Narrow gastric tube; Magnetic resonance; Functionality

1. Introduction

Radical esophagectomy represents the approach of choice in several surgical challenges, including esophageal carcinoma [1,2], high-grade Barrett’s esophagus [3], severe corrosive burns [4], and broad traumatic perforations [5]. Different reconstruction techniques are actually available to re-establish lumen continuity between the hypo-pharynx and the stomach: gastric pull-up is the most common procedure [6,7] while colon [8,9] or jejunum [10] interposition represents viable but less popular alternatives. Nevertheless, esophageal reconstructive surgery through gastric pull-up still exposes the patients to significant complications: ischemia, leak, and stricture of esophageal anastomosis are early comorbid conditions [7] which may worsen prognosis, while cough, bronchorrhea, and, most of all, functional disturbances (i.e., reflux, bolus stasis, delayed emptying) lately influence quality of life [11,12]. In the recent years, the esophageal reconstruction with narrow gastric tube (NGT) has been successfully introduced as an innovative modification of the original gastric pull-up technique by various studies [13,14]: the aim of this new approach is to obtain a lumen wide enough (>3 cm) to allow a physiological-like passage of solid food and yet narrow enough (<5 cm) to facilitate emptying, thus reducing the probability to develop functional alterations and relative symptomatology. In order to obtain proper evaluation of post-surgery leaks, strictures, or functional abnormality in patients with esophageal reconstruction, the imaging examination of choice is actually represented by conventional videofluoroscopy [15]. The constant technological progress in the field of magnetic resonance (MR) imaging, in addition to an increasing interest in developing new radiation-free modalities to obtain real-time evaluation of physiological processes, have recently disclosed the possibility to perform MR-fluoroscopic imaging of the esophageal functionality: at present, the employment and evolution of this interesting technique is limited to a few feasibility [16] and preliminary clinical studies mainly based
on the evaluation of esophageal motility disorders [17] but, to our knowledge, current literature completely lacks any evidence on post-surgery patients. The aim of our work was to assess the value of MR-fluoroscopy as potential long-term follow-up modality for the evaluation of functionality and morphology of the NGT in subjects who underwent radical esophagectomy.

2. Materials and methods

2.1. Patients population

Between January 2002 and December 2004, 10 patients (6 males, 4 females; mean age = 54 ± 10 years), hospitalized at the Division of Thoracic Surgery of our Institution, underwent trans-abdominal esophagectomy and esophageal reconstruction with NGT. Each subject was scheduled for post-surgery follow-up with videofluoroscopy examination at 3 days, 1 week, 1 month, 3 months and 6 months intervals: no post-surgery leaks, strictures, or disease recurrence were evidenced; in 4 patients, the videofluoroscopic control at 6 months interval documented functional abnormalities (including prolonged transit time, reflux and stasis of the contrast agent). Between October 2005 and January 2006, the same patients underwent esophageal MR-fluoroscopy as long-term follow-up examination (average time interval between intervention and MR-fluoroscopy = 2 years and 3 months). All patients gave written informed consent before inclusion in the study group and the whole protocol was approved by the Local Ethical Committee.

2.2. Surgical technique

After trans-abdominal radical esophagectomy and gastric mobilization (Fig. 1a), the restoration of alimentary continuity was obtained, in all cases, by gastric tubulization along the greater curvature through laparotomy, basing the vascular supply of the graft on the right gastro-epiploic vessels. The tube was prepared using a linear stapler and calibrated in order to obtain a diameter of 3—5 cm (Fig. 1b–d). In all cases only a simple finger stretching pyloroplasty was performed. Once completed (Fig. 1e), the NGT was then sutured with two or three silk stitches at the distal extremity and gently pulled up to the neck. The NGT and the proximal esophagus were then anastomosed with an endoscopic linear stapler (ETS45 blue cartridge, Ethicon Endo-Surgery) placed across the two opposite walls with the anvil on the esophageal lumen and the cartridge in the NGT.

2.3. MR-fluoroscopy patients preparation and contrast agent

All subjects fasted for at least 12 h in order to perform MR-fluoroscopy examination in basal conditions. Outside scan room, the ability of each patient to swallow a small amount of water in prone and supine position was tested to detect eventual aspiration, avoiding dangerous circumstances inside the magnet bore [17]. We used as oral contrast agent a mixture of semi-fluid yoghurt and Gd-DTPA 0.5 M, 1:100 (Multihance, Bracco SpA, Milano, Italy) [17]. All subjects were strictly instructed to swallow the contrast agent, during the exam, in a single act.

2.4. MR-fluoroscopy equipment and imaging protocol

The examinations were performed on a 1.5 T scanner (Magnetom Avanto, Siemens Medical Solutions, Erlangen, Germany; gradient strength 45 mT/m, Slew Rate 346 T/m/s, Rise Time 400 μs, featuring total imaging matrix-TIM™ technology), equipped with surface phased-array and integrated spine coils. Scans were acquired with the patients

![Fig. 1. Outcome of gastric mobilization after esophagectomy (a); gastric tube preparation and calibration using a plastic tube and a linear stapler (b–d); completed and calibrated narrow gastric tube sutured at its distal extremity (e).](image)

![Fig. 2. Appearance of the NGT on MR-fluoroscopy images acquired on the sagittal plane before contrast agent administration. The proximal (pharyngeal) and the distal (gastric) anastomosis (arrowheads) can be clearly depicted as narrowing of the lumen. This image is used to obtain a precise measurement of the antero-posterior caliber of the NGT from wall to wall (line).](image)
placed first in the prone and then in the supine position. The imaging protocol was divided in two steps: using a breath-hold TRUFI sequence (TR = 3.83 ms; TE = 1.92 ms; Thickness 4 mm; Number of slice 29) oriented on coronal and axial planes, a scout view of the thorax and upper abdomen was first obtained to visualize the position, the course, and the morphology of the NGT; thereafter, the MR-fluoroscopic imaging was performed during the transit of contrast agent boluses through the lumen of the gastric tube: a single slice slab T1-weighted Turbo-FLASH (TFL) sequence (TR = 600 ms; TE = 1.3 ms; Flip Angle 8°; Thickness 20 mm; FoV 350; Matrix 128 × 256; N. acquisition 120; TA = 50 s) was positioned with a median orientation on the center of the NGT lumen, using the TRUFI scout images to set the optimum slice angle. The parameters of the TFL sequence were modified in order to obtain real-time visualization of the functionality of the reconstructed esophagus. The current values of TR (600 ms), TE (1.3 ms), and Flip Angle (8°) allowed a temporal resolution of about 2.25 frames per second (fps). Immediately before the start of MR-fluoroscopic sequences, 10—15 ml of contrast agent was administered into the mouth of the patients with a 50 ml syringe connected to a silicone tube; the patients were instructed to swallow the entire bolus shortly after the onset of the audible gradient pulsations. We obtained five series of MR-fluoroscopic acquisitions: two acquired on the median sagittal plane and two on the median coronal plane to

Fig. 3. MR-fluoroscopy images acquired on the coronal plane (images have been sampled from the whole fluoroscopic acquisition); time intervals are at 2 (a), 4 (b), 6 (c), and 8 s (d) from sequence start. Pseudo-peristaltic contractions stripping the NGT in response to contrast agent boluses can be clearly depicted (arrows): the images demonstrate that the adequately re-established motility allows good lumen clearance after contrast agent administration.

Fig. 4. MR-fluoroscopy images acquired on the sagittal plane (images have been sampled from the whole fluoroscopic acquisition); time intervals are at 3 (a), 6 (b), 9 (c), and 12 s (d) from sequence start. The progression of the contrast agent bolus (arrows) form the proximal portion of the NGT to the sub-diaphragmatic stomach is regular; neither reflux, nor stasis is observed.

Fig. 5. MR-fluoroscopy images acquired on the oblique axial plane at the passage between the intra-thoracic NGT and the remaining sub-diaphragmatic stomach (images have been sampled from the whole fluoroscopic acquisition); time intervals are at 6 (a), 8 (b), 10 (c), and 12 s (d) from sequence start. The contrast agent bolus (arrows) reaches the distal extremity of the NGT, distends the anastomosis, and travels through the sub-diaphragmatic stomach.
visualize the functionality and the morphology of the reconstructed esophagus, and one on the oblique axial plane to depict the transit of contrast agent boluses at the passage between the intra-thoracic NGT and the remaining sub-diaphragmatic stomach.

2.5. Image analysis

MR-fluoroscopy images were reviewed in consensus by two radiologists (V.P., M.A.) with high level of experience in reporting videofluoroscopy examinations. To perform an optimal evaluation of esophageal motility, images were reviewed in cine mode. The findings were compared with those of a healthy control population. In each patient was assessed a standard set of morphological and functional parameters assigning a score for each reported value:

- NGT maximum caliber (Fig. 2): between 30 and 50 mm = 0; up to 60 mm = 1; >60 mm = 2;
- NGT motility (intended as pseudo-peristaltic contractions stripping the narrow gastric tube in response to contrast agent boluses) (Fig. 3): continue contractions = 0; isolate contractions = 1; no contractions = 2;
- Transit time of the contrast agent bolus (Fig. 4): <9 s = 0; between 9 and 15 s = 1; >15 s = 2;
- Evidence of reflux (Fig. 5): no reflux = 0; reflux = 1;
- Onset of contrast agent stasis inside the lumen (Fig. 6): no stasis = 0; stasis = 1.

The population was then divided in four groups depending on the score assigned to each parameter:

- GROUP I (no alterations) = total score 0;
- GROUP II (minimal alterations) = total score 1/3;
- GROUP III (moderate alterations) = total score 4/6;
- GROUP IV (severe alterations) = total score 7/8.

3. Results

Examinations were well tolerated in all cases and no sort of complication was experienced during contrast administration maneuvers and scan. Average room time, including patient preparation, was 22 ± 3 min. The whole NGT region, comprised between the cricopharyngeal sphincter and the sub-diaphragmatic stomach, was correctly visualized, acquiring good quality images in all subjects. No significant difference between the prone and the supine acquisitions was reported. Each patient was correctly assigned to a different score group (Table 1).

GROUP I: Three patients, who presented an excellent outcome after esophagectomy and NGT reconstruction (tube caliber below 50 mm, re-established motility with transit time below 9 s, no reflux, and no stasis) were assigned to the ‘no alterations’ group.

GROUP II: Two patients with NGT caliber superior to 50 mm and transit time between of 9 and 15 s (total score 2), one patient with reflux and only isolate contractions of the NGT (total score 2), and a further one with reflux (total score 1) were assigned to the ‘minimal alterations’ group.

GROUP III: One patient with NGT caliber superior to 60 mm, no contractions, and transit time of 20 s (total score 6) and another patient with no contractions, reflux, and stasis (total score 4) were assigned to the ‘moderate alterations’ group.

GROUP IV: Only one subject with NGT caliber of 65 mm, no contractions, transit time of 23 s, and stasis (total score 7) was assigned to the ‘severe alterations’ group.

Table 1

<table>
<thead>
<tr>
<th>Functional and morphological parameters in each patients group</th>
<th>GROUP I</th>
<th>GROUP II</th>
<th>GROUP III</th>
<th>GROUP IV</th>
<th>Total</th>
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<tr>
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<td>3</td>
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<td>1</td>
<td>—</td>
<td>6</td>
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<td>—</td>
<td>—</td>
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<td>—</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Continue NGT contraction</td>
<td>3</td>
<td>3</td>
<td>—</td>
<td>—</td>
<td>6</td>
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<tr>
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<td>—</td>
<td>2</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
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<td>2</td>
<td>1</td>
<td>—</td>
<td>6</td>
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<tr>
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<td>—</td>
<td>—</td>
<td>2</td>
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<tr>
<td>Transit time &gt; 15 s</td>
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<td>—</td>
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<td>1</td>
<td>2</td>
</tr>
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<td>1</td>
<td>—</td>
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<td>1</td>
<td>—</td>
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</table>
4. Discussion

4.1. Background

Follow-up protocols for patients who underwent gastrointestinal surgery include a wide range of diagnostic techniques: manometry [18], intraluminal multi-channel impedance [19], and pHmetry [20] are the main instrumental procedures required for a dedicated evaluation of the physiology alterations which may occur in the post-surgery period. Conventional videofluoroscopy, featuring the use of both high density barium and water soluble contrast agents, is the most solid imaging modality for the study of morphological and functional changes and surgery-induced conditions [21,22]; in particular, in patients with esophageal reconstruction after total esophagectomy [15], the optimal spatial resolution, in combination with the real-time image acquisition allowed by the modern fluoro-orthocliniscopes, have made videofluoroscopy the modality of choice in the evaluation of leaks, strictures, and functional abnormality. However, the exposure to radiation [23], the indirect-only visualization of soft tissue and the reactions related to contrast agent aspiration [24] still represent consistent drawbacks to videofluoroscopic exams. At present, no viable alternatives to conventional videofluoroscopy are available for the study of post-surgery patients. MR-fluoroscopy imaging of esophageal functionality has been recently developed in healthy volunteers and in subjects with esophageal motility disorders as a non-invasive and encouraging application of ultra-fast acquisition sequences.

4.2. Our experience

No evidence on the reliability of MR-fluoroscopy evaluation of esophageal functionality in post-surgery patients has ever been reported, and our work approaches this unexplored field focusing on the study of subjects who underwent esophagectomy with NGT reconstruction. Since now, different MR-fluoroscopy techniques have been introduced for the evaluation of esophageal functionality: in their paper [25], Barkhausen et al. first discussed the characteristics of TrueFISP sequences for the dynamic visualization of pharynx and upper esophagus, while other authors lately proposed T1-weighted Fast Field Echo/Turbo Field Echo [16], TurboFLASH [17], and Dynamic Gradient-Echo sequences for the MR-fluoroscopy imaging of esophageal functionality. For the study of patients with NGT reconstruction of the esophagus, we chose to adopt T1-weighted Turbo-FLASH sequences basing on the encouraging results reported in the evaluation of esophageal functionality in subjects with motility disorders [17]; since a just compromise between temporal and spatial resolution (highest possible frame rate with sufficient spatial definition) is the most critical factor to perform proper MR-fluoroscopy imaging, our primary objective was to set low values of repetition time (TR = 600 ms), Flip Angle (FA = 8°) and, consequentially, of sequence TA (50 s), maintaining at the same time an adequate matrix (125 × 256). Several different mixtures have been proposed as oral contrast agent for MR-fluoroscopy, ranging from ferric-ammonium solutions [16], to semolina pudding [25], yoghurt [17], or water mixed with Gadolinium: the yoghurt/Gadolinium mixture we used was an optimal solution providing excellent signal intensity with barium-like physical properties, and improving patient comfort with good compliance during examination. The combination of all these factors allowed real-time imaging of NGT functionality and morphology: the peculiar post-surgery changes occurring in patient with NGT reconstruction of the esophagus were correctly evaluated in all cases, yielding sufficient information to assign each patient to the corresponding score group. We demonstrated a strong association between low NGT caliber (which is the main target of the surgical procedure) and optimal NGT functionality, with re-established motility and short transit time; on the other hand, we also showed that an analogue association exists between raised NGT caliber (especially over 60 mm) and poor NGT functionality, including increase of transit time and contrast agent stasis. From a surgical point of view, these findings are probably related to the fact that a narrower tube offers more adequate mechanical performance than a wider one: the elastic energy produced by the wall straining at each bolus passage in the lumen, is returned in form of pseudo-peristaltic contractions by the smooth muscular layer; if wall straining is poor, or does not happen at all when a bolus passes (i.e., due to the over-distension of NGT), returning contraction will be weak or absent, thus causing an increase of the transit time and a stasis of the contrast agent in the lumen. These findings demonstrate that MR-fluoroscopy can be of some clinical impact in patients with NGT reconstruction for the evaluation of functionality outcome after surgery.

4.3. Advantages and limitations of the study

In a poorly explored field, as the MR-fluoroscopy imaging of the esophagus, each step in a new direction must be adequately considered. Indeed, our study confirms some points assured by precedent works and also introduces important novelties for the future development of this new technique: first of all, following the path of other studies, we confirmed that, at present, Turbo-FLASH sequences represent a good solution to obtain real-time imaging of esophageal transit, allowing near real-time acquisition in combination with good spatial resolution; moreover, the use of yoghurt added with Gadolinium as oral contrast agent provides an excellent emulation of foodstuff boluses for esophageal transit evaluation. On the other hand, we introduced a substantial novelty in comparison with other papers, demonstrating that the evaluation of functional characteristics of subjects who underwent esophageal surgery, and in particular of those with NGT reconstruction of the esophagus after esophagectomy, is feasible and that MR-fluoroscopy can properly investigate the peculiar alterations which may develop after this kind of intervention. Anyhow, we continue to deal with the well known limitations of MR-fluoroscopy: the spatial resolution of functional sequences, even if pushed to its actual limits, is still suboptimal for an accurate evaluation of subtle wall abnormalities, as commonly seen at videofluoroscopy, and need to be definitively implemented; the temporal resolution (2.25 fps), compared with that of X-ray (up to 25/30 fps), is still too low and actually cannot be raised without fatally impairing matrix values. Moreover, until high-field MR units...
with upright or tilting table will become widely installed, MR-fluoroscopy of the esophageal functionality can only be performed in the laying position, thus precluding the evaluation of the transit of contrast agent in true physiological conditions. This issue likely favored the motility of narrower tubes: probably, if all the patients were studied in the upright position, the wider gastric tubes may have shown a better functionality, even if not a completely re-established motility. A last non-technical limitation, which must be outmatched in next studies, is that we included in our population only long-term follow-up patient who underwent esophagectomy with NGT reconstruction: the early evaluation of patients treated with this and different surgical procedures, as in Nissen’s intervention, must be considered mandatory to obtain clinically significant results.

4.4. Conclusions

In conclusion, our study demonstrates that MR-fluoroscopic examination in patients who underwent esophagectomy with NGT reconstruction is feasible and can investigate NGT functionality, eventually evidencing the typical alterations that may develop in these subjects. Moreover, this imaging modality is rapid, non-invasive, reproducible, and without discomfort for patients. Since we have performed a long-term follow-up, the findings of our study reflect the true outcome of the intervention and of its influence on the quality of life in these patients. In perspective, MR-fluoroscopy could be considered as a useful complementary procedure for the follow-up of these patients, and should even be assessed in the evaluation of subjects who underwent different surgical procedures. An extensive study on a larger and heterogeneous population is necessary to achieve and consolidate more significant results in the evaluation of post-surgery patients.

References