Eur Radiol (2007) 17: 3123–3129
DOI 10.1007/s00330-007-0678-y

Tanja Fischer
Roland Ladurner
Alexander Gangkofer
Thomas Mussack
Maximilian Reiser
Andreas Lienemann

Functional cine MRI of the abdomen for the assessment of implanted synthetic mesh in patients after incisional hernia repair: initial results

Received: 16 September 2006
Revised: 7 March 2007
Accepted: 26 April 2007
Published online: 5 June 2007

T. Fischer · A. Gangkofer · M. Reiser · A. Lienemann
Department of Clinical Radiology, Ludwig-Maximilians-University Munich,
Ziemssenstrasse 1,
80336 Munich, Germany

R. Ladurner · T. Mussack
Department of Surgery and Traumatology, Klinikum Innenstadt, Ludwig-Maximilians-University Munich,
Nussbaumstrasse 20,
80336 Munich, Germany

T. Fischer (✉)
Department of Clinical Radiology, Klinikum Innenstadt, Ludwig-Maximilians-University Munich,
Nussbaumstrasse 20,
80336 Munich, Germany
e-mail: tanja.fischer@med.uni-muenchen.de
Tel.: +49-89-51609101
Fax: +49-89-51609102

Abstract The aim of our study was to develop a method that allows the vizualiation and evaluation of implanted mesh in patients after incisional hernia repair with MRI. Furthermore, we assessed problems typically related with mesh implantation like adhesions and muscular atrophy. We enrolled 28 patients after incisional hernia repair. In 10 patients mesh implantation was done by laparoscopy (expanded polytetrafluoroethylene=ePTFE mesh) and in 18 by laparotomy (polypropylene mesh). Functional MRI was performed on a 1.5-T system in supine position. Sagittal and axial TrueFISP images of the entire abdomen were acquired with the patient repeatedly straining. Evaluation included: correct position and intact fixation of the mesh, furthermore visceral adhesions, recurrent hernia and atrophy of the rectus muscle. The ePTFE mesh was visible in all cases; the polypropylene mesh was not detectable. In seven of the ten ePTFE meshes the fixation was not intact; two recurrent hernias were detected. Twenty of 28 patients had intraabdominal adhesions. In 5 cases mobility of the abdominal wall was reduced, and 16 patients showed an atropy of the rectus muscle. Functional cine MRI is a suitable method for follow-up studies in patients after hernia repair. ePTFE meshes can be visualized directly, and typical complications like intestinal adhesions and abdominal wall dysmotility can be assessed reliably.

Keywords Functional cine MRI · Intraabdominal adhesions · Incisional hernia · Mesh implantation

Introduction

Incisional hernias after open abdominal surgery occur in about 11% to 23% of the patients [1]. These hernias often need repeated surgical repair; the recurrence rates are high with 4–24% [2]. Many different operation techniques have been introduced for incisional hernia repair: either an abdominoplastic with direct suture or, recently preferred because of the lower recurrence rates, the implantation of synthetic mesh material via an open or laparoscopic approach [3–7]. The mesh is usually placed preperitoneally (open repair) or intraperitoneally (laparoscopic repair) at the back of the anterior abdominal wall, respectively the rectus muscle, often causing typical complications like seroma, intraabdominal adhesions, reduced abdominal wall mobility or muscle atrophy [8–10]. The formation of adhesions after mesh implantation is observed frequently in 20% to 55% of the patients [11], depending on the mesh type. Intraabdominal adhesions often result in chronic abdominal complaints, and they are the cause for 40–75% of all reoperations required for intestinal obstruction [12, 13]. In patients who underwent abdominal surgery hospital readmissions for disorders directly or possibly related to adhesions were necessary in 35% over the following 10 years [14], causing considerable costs for the health care systems [15]. For these patients a reliable non-invasive diagnostic method is desirable, because the only other alternative would be a repeated operation, causing an additional risk of new adhesions [16].

Up to now the evaluation of hernias and postoperative abdominal complications with imaging modalities is quite limited, and all available methods are restricted to certain aspects of these complex problems. Herniography is an established method for the detection of inguinal hernias, but it is an invasive method with application of contrast agent into the abdominal cavity; nowadays it is often replaced by ultrasound [17, 18]. Conventional enteroclysis is considered the standard radiological method for the detection of abdominal adhesions [19]; however, it is a very inconvenient, laborious and time-consuming examination. Besides, both methods are associated with a considerable radiation exposure. Therefore it is not suitable as a routine procedure in every patient or for follow-up studies. MR enteroclysis has also substantial limitations in the assessment of intraabdominal adhesions, because a change of the patient's position as well as external manual compression, which are mandatory for detecting adhesions, are not possible during MRI scanning. High resolution ultrasound for the detection of abdominal wall adhesions is based on the visceral slide produced by either respiratory movement or manual compression [20, 21]. Abdominal wall adhesions can be detected according to the restricted slide of the bowel loops along the anterior abdominal wall with a high sensitivity and specificity [22]. To achieve these good results, an experienced and well-trained investigator is mandatory. This method is limited to the assessment of adhesions at the anterior abdominal wall; the whole abdominal and pelvic cavity cannot be investigated, and the thin prothetic mesh material itself cannot be assessed at all because of the lack of echogenic properties [22]. On CT images the ePTFE mesh can be delineated directly like in our MR studies [23]. CT can also demonstrate typical adhesion-related complications like hernia recurrence, seroma or strangulated obstruction or bowel ischemia [24, 25]. But dynamic imaging of visceral slide should not be performed with CT due to the repeated considerable radiation exposure. On static (contrast-enhanced) CT images, adhesions cannot be detected directly in most cases, but can only be assumed due to indirect signs like scar tissue, sudden changes of the diameter of the bowel lumen or bowel conglomerations.

The aim of our study was to find out if functional cine MRI allows the direct visualization and assessment of the implanted mesh in patients after incisional hernia repair and furthermore if it can demonstrate simultaneously the typical problems related to mesh implantation.

Materials and methods

In 2003 and 2004 we enrolled 28 patients after incisional hernia repair with mesh implantation in our study. The time range between the hernia operation and the MR examination was 6 to 60 months (mean 35.7 months). Ten patients (mean age 56.6 years, range 42–68 years; 2 female, 8 male) had a laparoscopic intraperitoneal onlay mesh (IPOM) repair with an expanded polytetrafluoroethylene mesh (ePTFE, Gore-Tex® Dual Mesh Biomaterial, 1 mm; W.L. Gore & Associates, Inc., Medical Products Division, Flagstaff, AZ). The mesh was fixed with spiral titanium tackers to the peritoneum and posterior rectus muscle sheath. Eighteen patients (mean age 59.4 years, range 39–82 years; 6 female, 12 male) had undergone open hernia repair in the subfascial technique with a large pore-sized, low-weight polypropylene (PP) mesh (Vypro®; weight 55 g/m^2; Ethicon, Norderstedt, Germany) fixed with absorbable single sutures into the extraperitoneal retromuscular space underneath the rectus muscle.

Written informed consent was given by all patients. The ethical board of the university indicated that its approval was not required for this study.

Functional cine MRI

We was used with the imaging technique introduced by Lienemann et al. [26] for the detection and mapping of intraabdominal adhesions by functional cine MRI. MR imaging was performed with a 1.5-T system (Vision; Siemens Medical Solutions, Erlangen, Germany). The patients were examined in the supine position using a body array surface coil. A premedication, bowel opacification or intravenous contrast agent was not required. We used a single-slice snap shot technique employing a steady-state precession (True FISP) sequence (TR 5.8 ms, TE 2.5 ms; flip angle 70°; matrix 192×256; FoV 400 mm; section thickness 7 mm). One cycle included ten single-slice True-FISP sequences repeated at the same slice position. Time resolution was one image per 1.3 s. During the acquisition of the cycle the patient was asked to increase the intraabdominal pressure by straining and subsequently relaxing again. To cover the entire abdomen a coronal localizer with a superimposed grid was used for placing the consecutive cycles at a distance of 1.5 cm. Depending on the patient's size, 16 to 22 sagittally and 20 to 24 transversally orientated cycles were acquired resulting in a total amount of 350–450 images of the entire abdomen. The mean examination time was 30 min.

Image analysis

Image analysis included: (1) evaluation of the implanted mesh (depiction possible? position correct? fixation intact? seroma?) and (2) assessment of typical complications following hernia repair (adhesions, muscle atrophy, abdominal wall mobility, recurrent hernia). For the diagnosis of intraabdominal adhesions the following criteria were used: (1) in adhesions between bowel loops and adjacent organs (e.g., anterior abdominal wall, bladder, retroperitoneum), the separation is missing continuously during the complete straining cycle and the visceral slide is restricted; additionally a distortion of the organs or tethering may be seen; (2) adhesions between two or more bowel loops exhibit visceral slide during straining, but no separation, resulting in "branching" with characteristic X- or Y-like formations of the bowel loops, often combined with a deformation or thickening of the adjacent bowel walls. The exact localization of the detected adhesions was documented using a map with a field segmentation of the abdomen as shown in Fig. 1.

Furthermore, we evaluated morphological features and the function of the anterior abdominal wall. A reduced mobility was diagnosed if there was no anterior movement of the abdominal wall recognized in the axial cine loops, although the patient sufficiently increased the intraabdominal pressure proved by sliding of the abdominal organs. An atrophy of the rectus muscle was identified if a fatty degeneration with an increased signal intensity compared to the other abdominal wall muscles and/or a loss of more than 50% of the thickness of the rectus muscle on one side was found. We assumed a recurrent hernia if a local protrusion of either intraabdominal fat or bowel structures through the anterior abdominal wall within the region of the implanted mesh was present.

These criteria were assessed by two experienced radiologists by means of consensus reading. The readers were blinded to the type of operation and mesh. A cine mode was used for displaying the MRI data sets.

Results

The acquired MR images were meaningful in all cases; no artifacts were present that impaired the image analysis considerably.

Table 1 shows a summary of the MR findings concerning the mesh. The polypropylene mesh itself with its fixing sutures was not visible in any of the patients who had undergone open sublay repair. In two patients of this group, however, a hypointense, 4–5-mm-thick bumpy plate was found adjacent to the anterior abdominal wall indicating reactive scar tissue. One patient had a seroma indicating the net position indirectly. By contrast, the ePTFE mesh used with the laparoscopic operation technique was clearly visible in all ten patients. The mesh was delineated as a thin smooth hypointense foil lying behind the ventral abdominal wall, separated from it by a thin layer of fatty tissue. The fixating titanium tackers cause typical small susceptibility artifacts (Fig. 2). Only in three patients all these tackers were located in their intended position. In seven patients the tackers, especially at the lower border of the mesh, were identified quite distant from the backside of the rectus muscle within the intraabdominal fat tissue (Fig. 3). Yet the ePTFE mesh usually stayed in place, lying even, except in two patients in whom the mesh was wavy and crumpled.

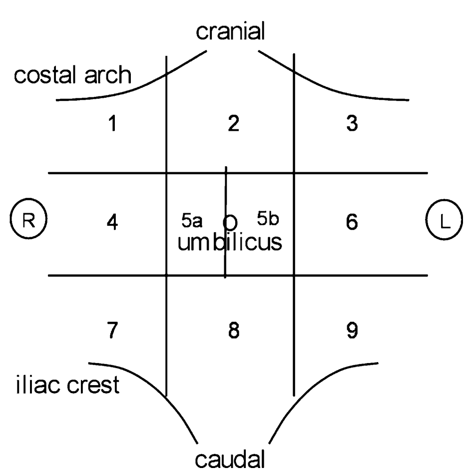

Fig. 1 Abdominal map with field segmentation (segments 1–9)

Table 1 Mesh morphology

MRI findings	ePTFE mesh; no. of patients* (n=10)	Polypropylen mesh; no. of patients* (n=18)
Mesh visible	10 (100)	0 (0)
Fixation intact	3 (30)	NA
Mesh crumpled	2 (20)	NA
Seroma around mesh	1 (10)	1 (6)

NA: not applicable
*Data in parentheses are percentages

Intraabdominal adhesions were found in 20 of the 28 patients (see Table 2) with 8 (80%) in the ePTFE group and 12 (67%) in the PP group. Adhesions between small bowel loops and the anterior abdominal wall were found in almost all patients with adhesions (19/20), independent of the type of surgery performed (Fig. 4). Five patients had additionally adhesions between two or more bowel loops, two patients between bowel loops and the retroperitoneum. Nine of the 20 patients exhibited adhesions in more than one location, resulting in a total number of 48 adhesions detected by functional MRI. The adhesions were mostly located in the midcentral segments 5a/b with a tendency to the right side, followed by the mid right segment 4 and lower central segment 8 (see Table 3).

Assessing the functional cine loops a remarkably reduced mobility of the anterior abdominal wall was recognized in 18% of all patients. Four of the five patients with a restricted mobility of the abdominal wall had an asymmetric atrophy of the rectus muscle; one had an additional fibrotic plate at the abdominal wall. Muscular atrophy with fatty degeneration of the rectus abdominis muscle, however, was also found in 12 patients with normal abdominal wall mobility. In 5 cases the atrophy affected both sides, and in 11 cases only one side (predominantly the right side) (Figs. 2b and 3b), without

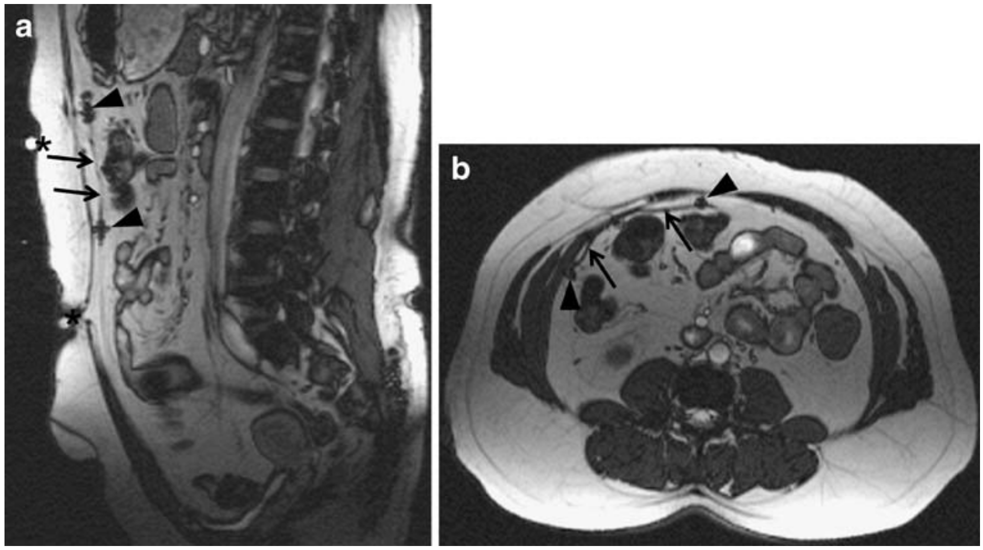

Fig. 2 **a** Midsagittal true FISP MR image of the abdomen. **b** Axial true FISP MR image of the abdomen. Patient after laparoscopic intraperitoneal onlay mesh repair. The ePTFE mesh (arrows) lies even and in the right position. The titanium tackers (arrowheads) fix the mesh to the anterior abdominal wall. Two water-filled capsules (asterix) are taped to the skin marking the scar. Note the atrophy of the right rectus muscle in the transverse image

a significant difference between the two patient groups. A recurrent hernia was detected by MRI in two patients after laparoscopic repair and in one patient after open sublay repair, the hernial sack containing mesenteric fat and in one case also small bowel.

Discussion

To our knowledge, our study is the first to visualize mesh morphology directly without radiation exposure. We found that only one of the used mesh types, the ePTFE mesh, was clearly visible in MR images, allowing an accurate assessment of the mesh itself and its fixing. A reason for this might be that the ePTFE mesh is microporous and hydrophobic, and therefore it is not going to be infiltrated by collagen tissue [11, 27, 28]. Moreover, this material is not absorbable, and the fixating titanium tackers are readily identified due to the small susceptibility artifacts. By contrast the PP mesh, fixated by resolvable sutures, is intended to be incorporated by fibrous connective tissue ingrowth forming an enduring tissue layer adjacent to the anterior abdominal wall [2, 11, 29]. Presumably due to this, it could not be identified on MR images several months after the operation. In the laparoscopic surgery group we found a large number of patients in whom the net fixation seemed not to be intact or the mesh was not found in the proper position in MRI. Our findings are in good agreement with the study by Toy et al., who found that staples or tackers alone provide an inadequate mesh fixation [30].

With functional MRI we suspected a high incidence of intraabdominal adhesions, in the ePTFE group even higher

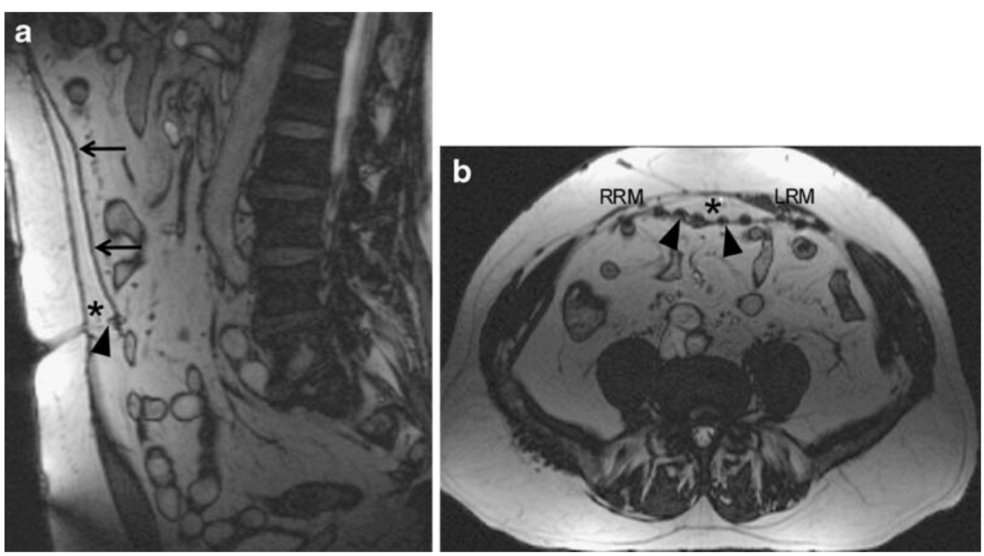

Fig. 3 **a** Midsagittal true FISP MR image of the abdomen. **b** Axial true FISP MR image at the lower border of the mesh. Displacemant of the titanium tackers (arrowheads) at the lower border of the ePTFE mesh (arrows) with interposition of fat tissue (asterix) between the mesh and anterior abdominal wall. Asymmetrical atrophy of the right rectus muscle (RRM) (LRM: left rectus muscle)

Table 2 MRI findings: frequency of typical complications after incisional hernia repair in the two patient groups

MRI findings	ePTFE mesh; no. of patients* (n=10)	Polypropylen mesh; no. of patients* (n=18)	Overall no. of patients* (n=28)
Recurrent hernia	2 (20)	1 (6)	3 (11)
Adhesions	8 (80)	12 (67)	20 (71)
Reduced mobility of abdominal wall	3 (30)	2 (11)	5 (18)
Atrophy of the rectus muscle	7 (70)	9 (50)	16 (57)

*Data in parentheses are percentages

Table 3 Distribution of the intraabdominal adhesions using the abdominal field segmentation (see Fig. 1)

Segment	No. of adhesions found in functional MRI
Upper right segment (1)	0
Upper center segment (2)	1
Upper left segment (3)	0
Mid right segment (4)	8
Mid center right segment (5a)	16
Mid center left segment (5b)	13
Mid left segment (6)	3
Lower right segment (7)	2
Lower center segment (8)	5
Lower left segment (9)	0
Total	48

than in the PP group. We had no surgical confirmation of our results. But in a previous study, functional cine MRI allowed detection and mapping of intraabdominal adhesions with a sensitivity and specificity of 87.5% and 92.5%, respectively, with intraoperative findings as standard of reference [26]. Koehler et al. found in 65 cases with re-operations after laparoscopic hernia repair in 91% either no or only filmy, avascular adhesions; severe cohesive adhesions were not found at all [31]. An explanation for this discrepancy between the operative findings and our MR results might be a higher sensitivity of MRI for less distinct adhesions [26], taking into account that Koehler had in fact found filmy grade 1 adhesions in 44 of 65 patients (68%) and grade 2 adhesions in 6 patients (9%). Other clinical studies as well as experimental studies in animals showed higher numbers of adhesions, too. Levrant et al. [16] found adhesions in 36% of 124 patients after abdominal surgery, in case of a midline laparotomy even in 59%. In a study with 30 rabbits, 16 weeks after mesh implantation Matthews et al. [11] found adhesions to the small intestine or omentum in 33 to 55%. Similar results were reported by Duffy et al. [32] with 53% adhesions after implantation of an ePTFE mesh in a porcine model.

The mentioned recurrence rates after incisional hernia repair are widespread throughout the literature with a range from 7 to 25% for open mesh repair and 0 to 9% for laparoscopic repair [3]. Taking into account the small

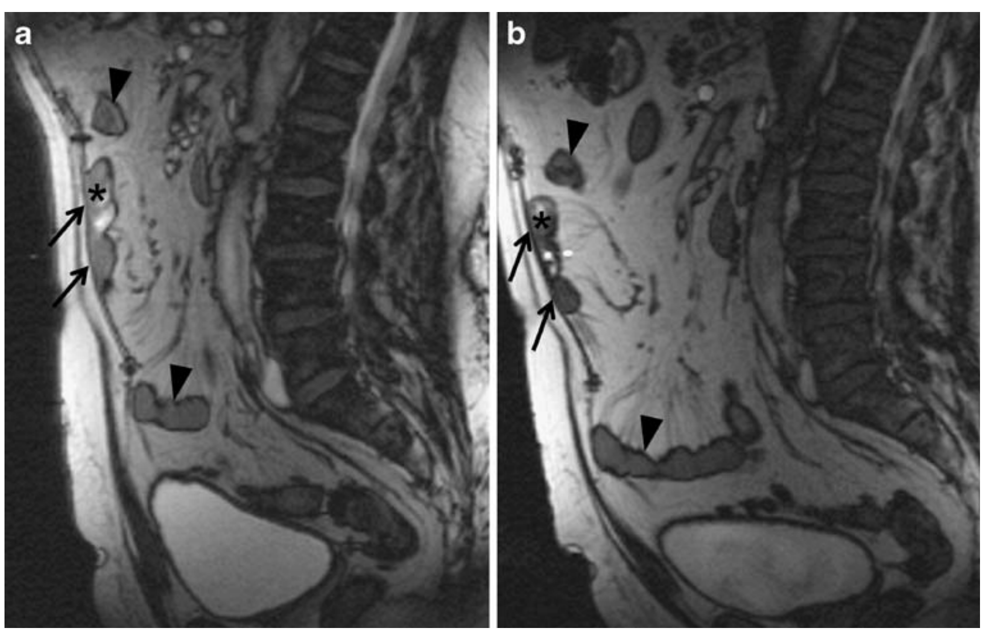

Fig. 4 **a** Midsagittal true FISP MR image of the abdomen at rest. **b** Midsagittal true FISP MR image of the abdomen at maximum straining. Broadbased adhesion of small bowel to the ePTFE mesh at the anterior abdominal wall. The small bowel loop (asterix) stays in a fixed position to the mesh without separation (arrows). In contrast, note the downward sliding of the other bowel loops (arrowheads) during straining

number of patients in our study groups, our findings for recurrent hernias with 20%, respectively 6%, lie within this range.

Muscular atrophy of the anterior abdominal wall as well as a reduced mobility are known to be typical long-term complications after abdominal surgery, even if there are only very few data available. In a study with 43 patients after open mesh repair of incisional hernias Machairas et al. [8] reported a restricted abdominal wall mobility in 7% on clinical examination. Our MR studies confirmed these findings, but showed an even higher percentage of 18% with reduced anterior abdominal wall mobility. The only published study addressing muscular atrophy of the anterior abdominal wall in MRI by Paajanen [33] indicated no obvious damage of abdominal muscles after mesh placement. Our data do not confirm this as we clearly saw an atrophy of the rectus muscle in 57% of our patients. From our data we saw no correlation between an intact or atrophic rectus muscle and a reduction of the mobility of the anterior abdominal wall. But all patients with a reduced mobility showed severe adhesions in more than one location between the anterior abdominal wall and bowel loops. Even if we could not detect interjacent fibrotic tissue directly, these findings might be an indirect hint for scar tissue and corresponding fibrosis.

A limitation of our study is the fact that there is no proven causality between the reported findings and the incisional hernia repair, as of course all patients had one or even several previous abdominal operations, from which the incisional hernia had resulted initially. During an operation for hernia repair an adhesiolysis is performed once adhesions are found. Therefore, we can assume that no adhesions existed immediately after incisional hernia repair. Therefore, the adhesions detected by MRI several months later are clearly related to the incisional hernia operation itself. Another restriction is the missing intraoperative validation for the dislocation of the mesh. But due to the very clear and sharp depiction of the ePTFE mesh and the fixing tackers in the MR images, we think our image interpretation is accurate. Concerning the other mentioned complications such as muscular atrophy or an immobile anterior abdominal wall, further studies immediately prior to and after the incisional hernia repair are necessary to separate the impact of this latest operation from the previous ones.

In conclusion, our study could demonstrate that functional cine MRI is the first non-invasive method to evaluate implanted ePTFE mesh used for laparoscopic hernia repair without radiation exposure. Although other mesh materials like polypropylene mesh could not be visualized directly, functional cine MRI provides an excellent and comprehensive evaluation of the typical complications related to all kinds of incisional hernia repair. Functional MRI may contribute to the understanding of the complex problems in this large patient group with incisional hernias.

References

1. Mudge M, Hughes LE (1985) Incisional hernia: a 10 year prospective study of incidence and attitudes. Br J Surg 72:70–71
2. Luijendijk RW, Hop WC, van den Tol MP et al (2000) A comparison of suture repair with mesh repair for incisional hernia. N Engl J Med 343:392–398
3. Cassar K, Munro A (2002) Surgical treatment of incisional hernia. Br J Surg 89:534–545
4. Heniford BT, Park A, Ramshaw BJ, Voeller G (2003) Laparoscopic repair of ventral hernias: nine years' experience with 850 consecutive hernias. Ann Surg 238:391–399; discussion 399–400
5. Koller R, Miholic J, Jakl RJ (1997) Repair of incisional hernias with expanded polytetrafluoroethylene. Eur J Surg 163:261–266
6. Morris-Stiff GJ, Hughes LE (1998) The outcomes of nonabsorbable mesh placed within the abdominal cavity: literature review and clinical experience. J Am Coll Surg 186:352–367
7. Schumpelick V, Conze J, Klinge U (1996) Preperitoneal mesh-plasty in incisional hernia repair. A comparative retrospective study of 272 operated incisional hernias. Chirurg 67:1028–1035
8. Machairas A, Misiakos EP, Liakakos T, Karatzas G (2004) Incisional hernioplasty with extraperitoneal onlay polyester mesh. Am Surg 70:726–729
9. Susmallian S, Gewurtz G, Ezri T, Charuzi I (2001) Seroma after laparoscopic repair of hernia with PTFE patch: is it really a complication? Hernia 5:139–141
10. Tagaya N, Mikami H, Aoki H, Kubota K (2004) Long-term complications of laparoscopic ventral and incisional hernia repair. Surg Laparosc Endosc Percutan Tech 14:5–8
11. Matthews BD, Pratt BL, Pollinger HS et al (2003) Assessment of adhesion formation to intra-abdominal polypropylene mesh and polytetrafluoroethylene mesh. J Surg Res 114:126–132
12. Menzies D (1993) Postoperative adhesions: their treatment and relevance in clinical practice. Ann R Coll Surg Engl 75:147–153
13. Ellis H (1998) The magnitude of adhesion related problems. Ann Chir Gynaecol 87:9–11
14. Ellis H, Moran BJ, Thompson JN et al (1999) Adhesion-related hospital readmissions after abdominal and pelvic surgery: a retrospective cohort study. Lancet 353:1476–1480
15. Wilson MS, Menzies D, Knight AD, Crowe AM (2002) Demonstrating the clinical and cost effectiveness of adhesion reduction strategies. Colorectal Dis 4:355–360
16. Levrant SG, Bieber EJ, Barnes RB (1997) Anterior abdominal wall adhesions after laparotomy or laparoscopy. J Am Assoc Gynecol Laparosc 4:353–356
17. Kahn AM, Hamlin JA (2006) Herniography: a valuable diagnostic modality. Hernia 10:372
18. Robinson P, Hensor E, Lansdown MJ, Ambrose NS, Chapman AH (2006) Inguinofemoral hernia: accuracy of sonography in patients with indeterminate clinical features. AJR Am J Roentgenol 187:1168–1178

19. Ott DJ, Chen YM, Gelfand DW, Van Swearingen F, Munitz HA (1985) Detailed per-oral small bowel examination vs. enteroclysis. Part II: Radiographic accuracy. Radiology 155:31–34
20. Kodama I, Loiacono LA, Sigel B et al (1992) Ultrasonic detection of viscera slide as an indicator of abdominal wall adhesions. J Clin Ultrasound 20:375–380
21. Sigel B, Golub RM, Loiacono LA et al (1991) Technique of ultrasonic detection and mapping of abdominal wall adhesions. Surg Endosc 5:161–165
22. Balique JG, Benchetrit S, Bouillot JL et al (2005) Intraperitoneal treatment of incisional and umbilical hernias using an innovative composite mesh: four-year results of a prospective multicenter clinical trial. Hernia 9:68–74
23. Gossios K, Zikou A, Vazakas P et al (2003) Value of CT after laparoscopic repair of postsurgical ventral hernia. Abdom Imaging 28:99–102
24. Balthazar EJ, Liebeskind ME, Macari M (1997) Intestinal ischemia in patients in whom small bowel obstruction is suspected: evaluation of accuracy, limitations, and clinical implications of CT in diagnosis. Radiology 205:519–522
25. Ha HK, Kim JS, Lee MS et al (1997) Differentiation of simple and strangulated small-bowel obstructions: usefulness of known CT criteria. Radiology 204:507–512
26. Lienemann A, Sprenger D, Steitz HO, Korell M, Reiser M (2000) Detection and mapping of intraabdominal adhesions by using functional cine MR imaging: preliminary results. Radiology 217:421–425
27. Bauer JJ, Harris MT, Kreel I, Gelernt IM (1999) Twelve-year experience with expanded polytetrafluoroethylene in the repair of abdominal wall defects. Mt Sinai J Med 66:20–25
28. Goldberg JM, Toledo AA, Mitchell DE (1987) An evaluation of the Gore-Tex surgical membrane for the prevention of postoperative peritoneal adhesions. Obstet Gynecol 70:846–848
29. Amid PK, Shulman AG, Lichtenstein IL, Hakakha M (1994) Biomaterials for abdominal wall hernia surgery and principles of their applications. Langenbecks Arch Chir 379:168–171
30. Toy FK, Bailey RW, Carey S et al (1998) Prospective, multicenter study of laparoscopic ventral hernioplasty. Preliminary results. Surg Endosc 12:955–959
31. Koehler RH, Begos D, Berger D et al (2003) Minimal adhesions to ePTFE mesh after laparoscopic ventral incisional hernia repair: reoperative findings in 65 cases. Zentralbl Chir 128:625–630
32. Duffy AJ, Hogle NJ, LaPerle KM, Fowler DL (2004) Comparison of two composite meshes using two fixation devices in a porcine laparoscopic ventral hernia repair model. Hernia 8:358–364
33. Paajanen H, Hermunen H (2004) Long-term pain and recurrence after repair of ventral incisional hernias by open mesh: clinical and MRI study. Langenbecks Arch Surg 389:366–370