Eur Radiol (2007) 17: 2044–2054
DOI 10.1007/s00330-007-0613-2

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Detection of recurrent rectal cancer with CT, MRI and PET/CT

Received: 4 December 2006
Revised: 7 February 2007
Accepted: 9 February 2007
Published online: 3 April 2007

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Abstract Computed tomography (CT), magnetic resonance imaging (MRI) and positron emission tomography (PET) all have the potential to directly visualize local and distant relapse of colorectal cancer (CRC). Nevertheless, the role of diagnostic imaging for routine follow-up of CRC patients remains controversial. Although MRI and PET have advantages over CT in the detection of local recurrence, until now only a few surveillance programs recommend the use of annual CT for routine follow-up. The objective of this review is to elucidate the current status of diagnostic imaging for the detection of recurrent rectal cancer based on the recent literature and our own experience. Furthermore, an insight into contemporary surveillance programs and an outlook concerning a novel technical approach to moving-table MRI at 1.5 Tesla for staging purposes are given.

Keywords Rectal cancer · Staging · Imaging techniques

Introduction

Colorectal cancer (CRC) is the third leading cancer type in the United States among both the male and female population with an estimated 148,610 new cases, and responsible for approximately 55,170 deaths in 2006 [1]. Eighty percent of CRC patients present with local disease amenable to surgery with curative intent [2]. Unfortunately, around 40% of these patients will develop recurrent cancer, mainly within the first three years [3–5]. One of every five patients will go on to develop liver metastases, and one out of every 12 patients will develop lung metastases [6]. Concerning rectal cancer, pelvic recurrence remains a significant problem, occuring in 3–47% of patients [7, 8]. Relapse after initial surgery for CRC is responsible not only for significant morbidity and mortality but also for impaired quality of life [9, 10]. In contrast to other malignancies, both local recurrence and metastatic spread from CRC can be addressed by curative-intent surgery. However, only 20–30% of patients with local relapse detected during follow-up have tumors that are deemed resectable at the time of diagnosis [11]. Aggressive surgical approaches for CRC recurrence confined to a single organ are associated with a 5-year survival rate of up to 30% in selected patient populations [3, 4, 8, 12]. Thus, early diagnosis of local recurrence and small volume metastases are two of the primary goals of surveillance strategies because salvage surgery clearly has a higher chance of success in the asymptomatic patient with limited disease [3, 12]. Consequently, surveillance should enhance the proportion of resectable cases to increase survival. In rectal cancer the majority of local recurrences originate from the tumor bed, which underlines the importance to directly visualize the perirectal tissues as part of postoperative follow-up [8]. Besides carcinoembryonic antigen (CEA) monitoring and endoscopy, CT, MRI and PET are diagnostic imaging modalities for the detection of local and distant relapse of CRC. Until now, the role of diagnostic imaging for routine follow-up of CRC patients remains controversial, since no single strategy of postoperative surveillance has been unequivocally shown to improve survival or cure rate [13–15]. Only two [16, 17] of the currently existing six randomized studies [16–21] demonstrated significant improvement in survival for those patients receiving intensive surveillance but the definition of intensive varies widely among those trials [3]. The

findings were corroborated by three high-quality recent meta-analyses [22–24], suggesting survival benefit for intensive follow-up. Patients with more intensive postoperative surveillance including thoracic and abdominal imaging studies were more likely to have surgery for metastatic or recurrent disease [22–24]. The objective of the following article is to highlight the potential of diagnostic imaging for recurrent rectal cancer. In addition, an overview of current surveillance recommendations will be given, and important clinical trials in this context will be presented.

Postoperative surveillance programs for CRC

Surveillance strategies for CRC patients are heterogenous and vary among countries, institutions, and protocol-specific follow-up of clinical trials. Despite numerous trials, objective data by which to judge surveillance programs are scarce [3, 4]. In the growing atmosphere of cost consciousness in health care, it is imperative that current and future surveillance programs are based on solid data [4]. So far, six single-center randomized clinical trials and three meta-analyses exist (Tables 1, 2). In four of the six randomized trials, "liver imaging" was performed [16–18, 21]. The major result of the three recent meta-analyses of these randomized trials is a survival benefit under intensive surveillance [22–24]. Additionally, the results of two current prospective clinical trials support the use of imaging as part of follow-up policy for early detection of recurrence [3, 25].

The three fundamental subjects of postoperative surveillance programs are as follows [4]:

- detection of potentially curable recurrence
- detection of metachronous colorectal neoplasms
- assessment of the efficacy of diagnostic tests and therapy.

Table 1 Randomized trials of post-treatment follow-up in CRC

Study	Location (years)	5-year survival rate (%) [recurrence rate (%)]	
		Less intensity	More intensity
Makela et al. [18]	Finland (1988–1990)	54 (39)	59 (42)
Ohlsson et al. [19]	Sweden (1983–1986)	67 (33)	75 (32)
Kjeldsen et al. [20]	Denmark (1985–1994)	68 (26)	70 (26)
Schoemaker et al. [21]	Australia (1984–1990)	70	76
Pietra et al. [16]	Italy (1987–1990)	58 (19)	73 (25)
Secco et al. [17]	Italy (1988–1996)	48 (53)	63 (57)

CEA

CEA represents a glycoprotein oncofetal tumor-associated antigen being expressed by more than 90% of colorectal adenocarcinomas, but it is not increased in the serum of more than 90% of patients [26]. As a tumor marker, CEA is used to monitor patients for recurrent disease after curative resection of CRC. It still remains controversial whether increased CEA levels lead to early detection of tumor recurrence and will improve long-term survival [4]. Furthermore, 30% of all CRC recurrences do not produce CEA [27].

The 2005 update of the American Society of Clinical Oncology (ASCO) [5] guideline for CRC surveillance recommends CEA testing every 3 months for at least 3 years after diagnosis in patients with stage II and III disease, if the patient is a candidate for surgery or systemic therapy. The European Society for Medical Oncology (ESMO) [28–30] proposes CEA determination every 3–6 months for 3 years and every 6–12 months year 4 and 5 after surgery, if initially elevated. Interestingly, it is stated that clinical, laboratory, and radiological examinations are of unproven benefit and shall be restricted to patients with suspicious symptoms which is in contrast to the above mentioned goals of surveillance.

Chest radiograph

It is known that 5–10% of patients who undergo resection for CRC will develop lung metastasis. Due to encouraging results of resection of pulmonary metastasis from CRC, it is imperative to detect lesions as early as possible [4, 19, 21, 31]. On the basis of the available data ASCO [5] and ESMO [28–30] do not support yearly chest X-ray in the follow-up of CRC patients.

CT

According to the updated ASCO guideline, patients who are at higher risk of recurrence, and who could be candidates for curative-intent surgery, should undergo annual CT of the chest and abdomen for 3 years after initial therapy of CRC [5]. Additionally, a pelvic CT should be considered for rectal cancer surveillance [5]. The major reason why CT is now recommended is that all three recent meta-analyses reported a survival benefit for liver imaging [28–30]. In line with these analyses is a prospective single-center study [25] reporting on the surveillance of 530 patients who participated in a randomized clinical trial for Stage II and III CRC. The patients received CEA testing and CT scans of the chest, abdomen and pelvis as protocol-specific follow-up. A nearly identical number of relapses were detected by CEA and CT, but the CT-detected group had improved survival. The chest CT was added for several reasons. First, while in the study the greatest number of

Table 2 Meta-analyses of CRC post-treatment surveillance randomized clinical trials

Meta-analysis (year)	No. of articles	Pooled no. of patients across trials		Pooled 5-year mortality rate (%)		Absolute risk difference (%)	Effect on 5-year mortality
		Control	Intervention	Control	Intervention		
Figueredo et al. (2003) [22]	6	821	858	37	30	7	Relative risk 0.80
Renehan et al. (2002) [23]	5	676	666	37	30	7	Relative risk 0.81
Jeffery et al. (2002) [24]	5	676	666	37	30	7	Odds ratio 0.67

recurrences was found by abdominal CT imaging, the largest proportion of resectable recurrences was detected on the chest CT. Second, pulmonary recurrences were less likely to have elevated CEA values. Third, lung recurrences were found to be as common as liver relapses in rectal cancer patients and represented the largest proportion of resected metastases in the Intergroup 0114 trial [32]. A recent investigation by Arriola et al. [3] was conducted to evaluate the efficacy of the institutional follow-up policy. Data of 583 patients were analyzed. During follow-up, 208 (36%) recurrences were detected. Only 13% (n=26) of the recurrences were locoregional and 74% (n=154) were distant. In 28% of all recurrences, the only site of tumor relapse was confined to the liver. In 73 of the 208 patients with recurrent CRC, salvage surgery was performed. The median overall survival of all patients with relapse was 18 months. In contrast, the median overall survival of patients who underwent salvage surgery was 62 months. Only 32% of recurrences detected by CEA were resectable. The proportion of resectable cases increased to 50–60% in patients whose recurrence was detected by imaging techniques (abdomino-pelvic CT, chest X-ray, liver ultrasound). In the study imaging contributed to earlier detection of recurrence, and therefore, to a larger number of resectable cases.

MRI and PET

ASCO [5] and ESMO [28–30] do not recommend MRI and PET imaging for routine use inside surveillance programs for recurrent CRC.

Risk-adapted surveillance for CRC patients

To advance the idea of risk-adapted follow-up, Secco et al. [17] randomly assigned patients with two different risk profiles to intensive and minimal follow-up. Patients were preoperatively judged at high risk for recurrence if they had adenocarcinoma of the low rectum treated by low anterior resection, a preoperative CEA value≥7.5 ng/ml, Dukes C stage, poorly differentiated carcinoma (G 3), and mucinous adenocarcinoma or signet ring cells. Patients in none of these categories were considered at low risk. The results of this trial clearly show that prospective stratification of CRC patients in subgroups at higher and lower risk of recurrence according to established prognostic factors would be rational and clinically reliable, since patients classified as being at high risk developed recurrence 2.5-times more frequently than patients at low risk. Only patients at high risk who were randomly assigned to the minimal follow-up group had a shorter median disease-free intervall compared with high-risk patients who underwent intensive surveillance. The proposed risk-adapted follow-up strategy allowed for a significantly higher number of curative-intent surgical procedures and helped to reduce costs.

Imaging for recurrent rectal cancer

Local recurrence is defined as clinical, radiologic, and/or pathologic determination of rectal cancer recurrence in the prior pelvic treatment field [13]. In line with Abulafi and Williams [7], local relapse can be further divided into extraluminal recurrence (Fig. 1a–c), in which tumor regrowth occured in and around the tumor bed (Figs. 2, 3a–c), including the pericolic fat (Fig. 4a,b), the adjoining mesentery, and lymph nodes, and intramural recurrence, in which the tumor regrowth involved the region of the bowel anastomosis. Distant recurrence is defined as clinical, radiologic, and/or pathologic determination of rectal cancer recurrence at any other site, mainly liver, lung and retroperitoneum [13]. Recently, one of the largest single-institution analyses of long-term oncologic outcome of 297 patients with locally advanced rectal cancer Guillem et al. [13] observed a total of 67 patients (23%) with either local or distant relapse and a 10-year overall survival rate of 58%.

Two major problems of reporting on the value of state-of-the-art cross-sectional imaging for recurrent rectal cancer exist. First, there is a lack of reliable data comparing CT, MRI and PET. Second, current recommendations for postoperative surveillance of CRC patients neither include MRI nor PET. In general, diagnostic imaging for postoperative surveillance of CRC should have the potential to differentiate between scar and extraluminal recurrence, and of course, to detect anastomotic recurrence. To guide salvage surgery, an anatomically correct description of the location and extent of relapse is essential. Additionally, staging for metastatic spread should be possible within one examination, rendering a multi-modality approach unnec-

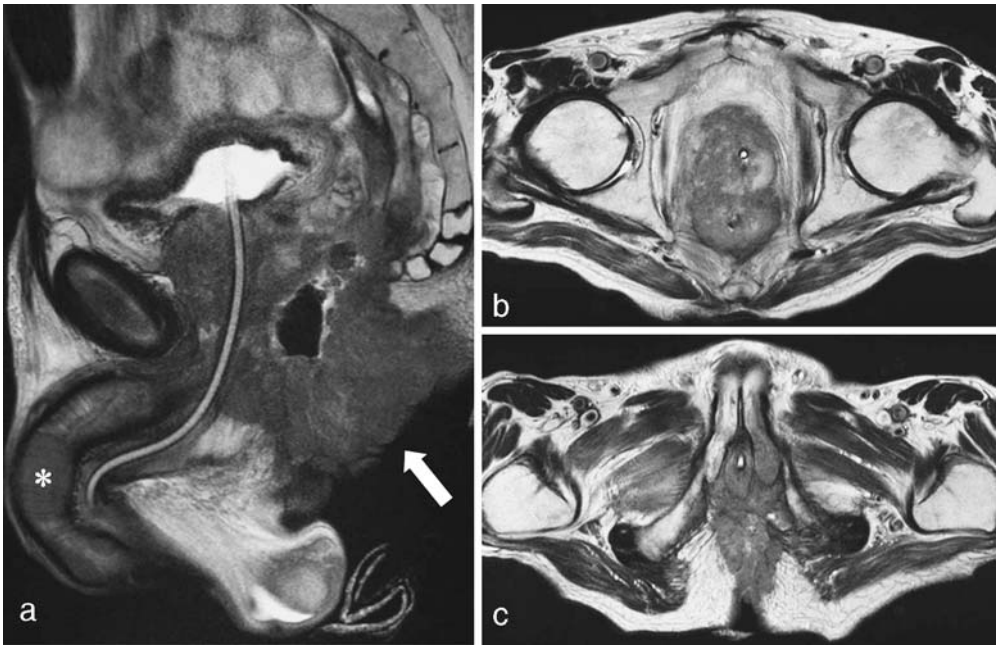

Fig. 1a–c Pelvic MRI. **a** Sagittal T2-weighted TSE image demonstrates extensive local recurrence from rectal cancer with central, superinfected, air-filled cavitation (*arrow*) and metastatic spread to the cavernous body (*asterisk*). **b** Axial T2-weighted TSE images show invasion of the prostate gland, and **c** the penile root

essary [33]. In this respect, one diagnostic challenge for CT, MRI, and PET in detecting recurrence consists of the alteration of the pelvic anatomy associated with previous surgery and chemoradiation therapy.

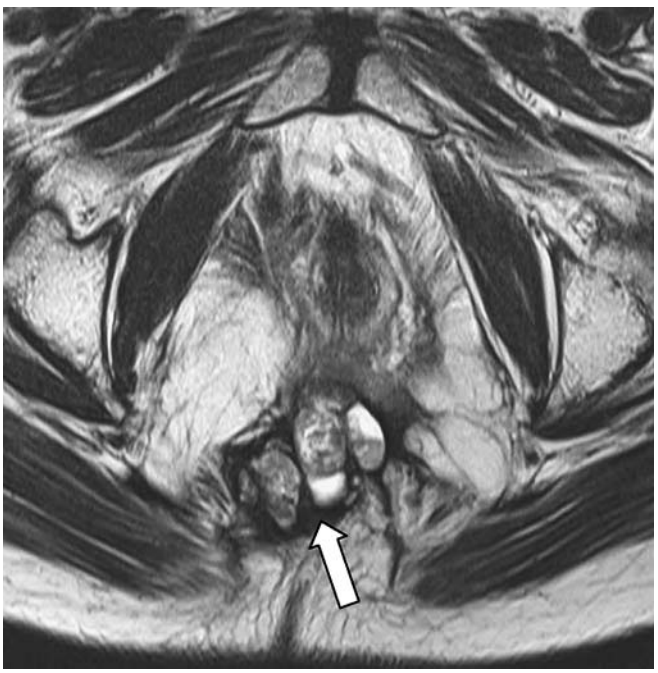

Fig. 2 Pelvic MRI. On the para-axial T2-weighted TSE sequence local recurrence from mucinous adenocarcinoma inside the scar following abdominoperineal resection can be identified demonstrating inhomogenously hyperintense signal (*arrow*)

Assessment of local relapse of CRC

CT

To date, CT is the preferred method for diagnosing local recurrence of CRC [4]. Few data exist elucidating the role of multi-slice CT (MSCT) for staging of recurrent rectal cancer [34, 35]. In a recent study [34] with 83 patients the sensitivity and specificity of MSCT for diagnosing pelvic recurrence in the second postoperative examination was 82% and 97%, respectively, if multiplanar reconstructions were routinely performed. Twenty-five patients were enrolled in a study by Blomqvist et al. [36] and received CT, MRI and CEA scintigraphy for the detection of recurrent rectal cancer. As a result of the study, MRI was the most effective imaging modality with an accuracy of 87.5% compared with CT, which correctly diagnosed recurrent cancer in 76%. In a comparative study, Pema et al. [37] analyzed the value of CT and MRI in diagnosing recurrent rectal cancer. Eighteen patients were included in this study. MRI was the superior imaging method with a sensitivity of 91%, a specificity of 100%, and an overall accuracy of 95%. CT reached a sensitivity of 82%, a specificity of 50%, and an accuracy of 68%. Studies [16, 18, 21, 31, 38, 39] demonstrating the use of CT imaging (Fig. 5a–d) in postoperative surveillance are summarized in Table 3.

Pelvic MRI

MRI is one of the leading imaging modalities for detecting pelvic recurrence of CRC [40–43], in our opinion currently the best, due to its excellent soft-tissue resolution,

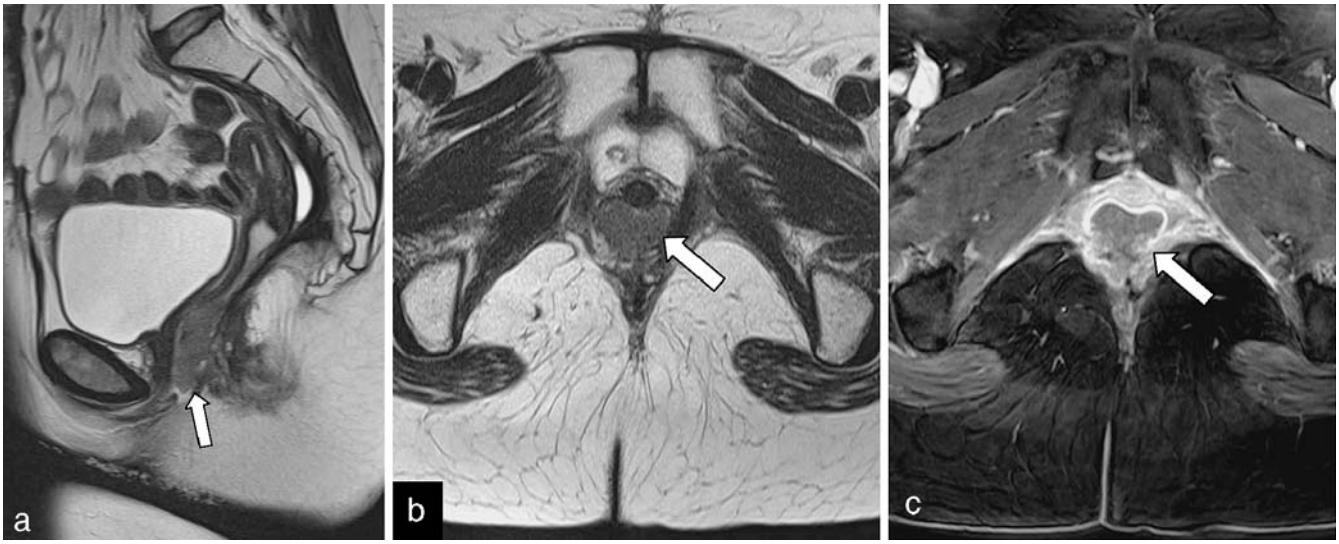

Fig. 3a–c Example of an extraluminal recurrence involving the vagina. **a** Hypointense presacral scar with a small seroma is seen on sagittal T2-weighted TSE image. Also, tumor inside the vagina can be depicted causing fluid retention (*arrow*). **b** Para-axial T2-weighted TSE image and **c** axial contrast-enhanced 3D-VIBE image show the intravaginal tumor recurrence (*arrows*)

providing detailed anatomic information. Compared with CT, the distinction of recurrent cancer within a presacral scar is more accurate. This finding is based on differences in signal intensity between tumor and fibrosis using T2-weighted sequences or contrast-enhanced imaging techniques [43] (Fig. 6a–d). Despite these advantages over other imaging tests, a recent study [8] concluded that the use of MRI as part of routine pelvic surveillance after curative resection of CRC is not justified. Instead, MRI should be reserved for selectively imaging patients with clinical, colonoscopic, and/or biochemical suspicion of recurrent disease. The study examined 226 patients who underwent curative surgery for CRC. An intensive follow-up program included clinical examination, CEA measurements, colonoscopy, and MRI at 3- to 6-month intervals. The separate contribution of these diagnostic tests to the final diagnosis was assessed. The median clinical follow-up was 42 months, with a median MRI surveillance period of 21 months, and a median number of MRI scans per patient of 3. Local recurrence was detected in 30 of 226 patients (13%). The median interval between initial surgery and recurrence was 15 months. MRI detected 26 (87%) of the 30 local recurrences and missed three of the four anastomotic recurrences. In summary, the sensitivity, specificity, the positive (PPV) and negative (NPV) predictive values were 87%, 86%, 48% and 98%, respectively. MRI was the only positive diagnostic test in four (13%) patients with pelvic recurrence located in the perirectal tissue. Only two of these patients were deemed to have resectable disease. Resection of local relapse was

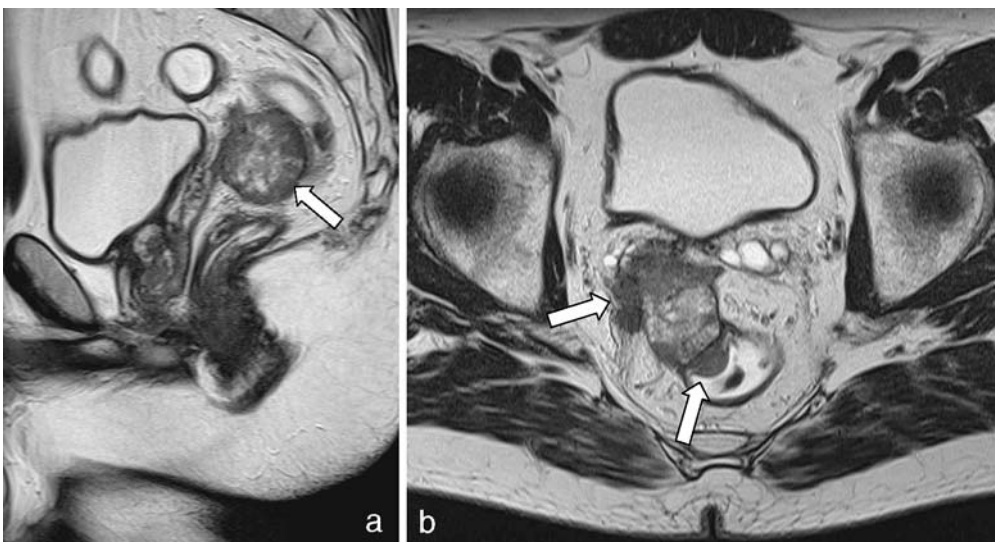

Fig. 4a, b Extraluminal recurrent colorectal cancer in the perirectal fat. **a** Sagittal T2-weighted TSE sequence reveals tumor nodule in the mesorectal fat (*arrow*). **b** On the para-axial T2-weighted TSE sequence tumor invasion of the right seminal vesicles and the rectal wall can be observed (*arrows*)

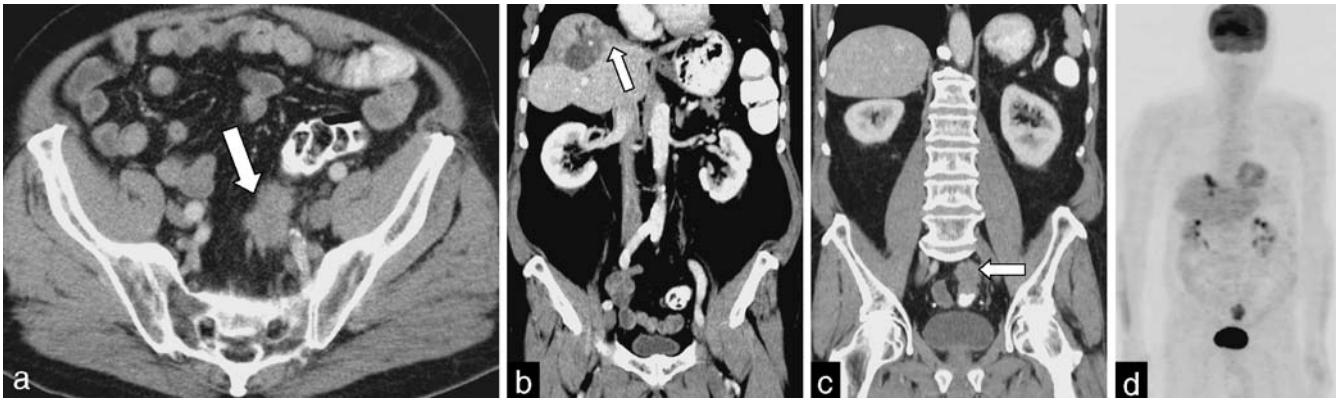

Fig. 5a–d Follow-up examinations of a patient with recurrent rectal cancer. **a** On the axial MSCT image extraluminal local tumor recurrence is seen on the left side (*arrow*). The coronal reconstructions reveal both **b** recurrent liver metastasis adjacent to the area of coagulation necrosis following RFA (*arrow*) and **c** the local extraluminal relapse already involving the bowel wall (*arrow*). **d** Corresponding PET image confirms the CT findings: metastatic lesion in the residual liver after hemihepatectomy and RFA, and a second presacral lesion with increased activity

possible in six (20%) patients. MRI correctly diagnosed four of these six cases. The median survival time in the surgically treated group was 13 months. In contrast, the median survival time of the unresectable patient group (n= 24) was 9 months. In light of these results, the authors strongly question the use of MRI in the routine postoperative follow-up of CRC patients. Five-hundred and seventy-six examinations were performed in the 226 patients in order to detect four (<2%) cases with local recurrence missed by other tests. To our knowledge, this is the first report addressing the role of pelvic MRI for postoperative surveillance of CRC patients.

PET/CT

CRC is known to be ^{18}F-fluorodeoxyglucose (FDG) avid [44]. PET is an accurate modality for detecting pelvic recurrence in rectal cancer patients [45], and may have advantages over CT and MRI in differentiating scar from viable tumor [46] (Fig. 7a–d). The reported accuracy of FDG-PET for pelvic recurrences of CRC ranges from 74% to 96%, and for metastatic disease to the lungs and liver, the accuracy ranges from 93% to 99% [47]. In a retrospective study, Moore et al. [48] investigated the impact of PET for the detection of pelvic recurrence of 60, previously irradiated rectal cancer patients. PET imaging correctly identified 16 of the 19 documented recurrences. The sensitivity, specificity, overall accuracy, PPV, and NPV were 84%, 88%, 87%, 76% and 92%, respectively. Even-Sapir et al. [49] assessed the role of PET/CT in the detection of local recurrence of rectal cancer. Sixty-two patients underwent PET/CT examination. PET/CT findings were of clinical relevance in 29 of the 62 patients. PET/CT was found to be more sensitive and specific as PET alone. Of 24 patients with pelvic recurrence, 16 had only pelvic recurrence, and eight had both pelvic and extrapelvic recurrence. Thirteen of the 24 patients were referred for surgery, and thereby, PET/CT correctly depicted 23 of the 24 pelvic recurrences. Additionally, extrapelvic metastases were found in 27 patients. In the study, PET/CT allowed to differentiate benign lesions from presacral recurrences with a sensitivity of 100% and a specificity of 96%. One point of critisism is that histologic diagnosis was possible in only 30 of 81 analyzed lesions.

Unfortunalety, PET has still some limitations. The detectability of tumor depends on tumor size and FDG-uptake [45]. PET cannot identify small volume disease due its well known limitations in spatial resolution of around 4–6 mm [50]. PET has demonstrated low sensitivity for lymph node staging in rectal cancer [50]. Mucinous adenocarcinomas have poor FDG-uptake [51]. Radiation-induced inflammation in the first 12 months after radiotherapy reduces specificity, whereas sensitivity is limited in patients receiving chemotherapy because tumor tissue might not be metabolically active [48]. Additionally, physiologic FDG uptake in displaced pelvic organs like bladder, small bowel loops, seminal vesicles, and uterus is responsible for false-positive interpretations [49]. Costs and availability are further disadvantages of

Table 3 Use of CT as first indicator of recurrent CRC

Study	No. of patients	CT as first indicator of recurrence (%)
Makela et al. [18]	106	9
Deveney and Way [39]	65	9
Bleeker et al. [31]	213	41
Castells et al. [38]	199	11
Schoemaker et al. [21]	325	1
Pietra et al. [16]	207	4

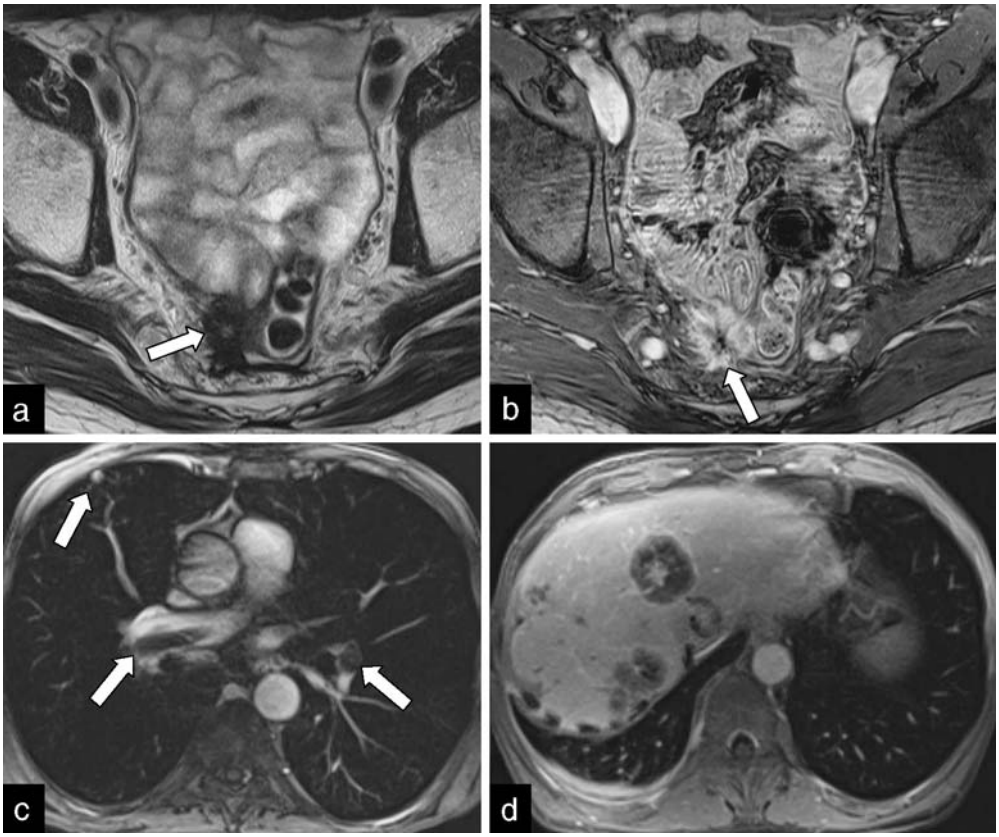

Fig. 6a–d Example of typical MR findings in a patient with extraluminal local and distant recurrences from rectal cancer. The presacral scar has a pathologic signal on both **a** para-axial T2-weighted image and **b** corresponding contrast-enhanced 3D-VIBE image, suggesting growing tumor (*arrows*): a central hyperintensity is seen on the T2 image, whereas inhomogenous enhacement can be observed on the VIBE image, while the center of the stellated scar remains hypointense. **c**, **d** The axial contrast-enhanced TimCT-FLASH images derived from one-stop staging during plevic MRI demonstrate a small lung metastasis (**c**), pulmonary embolism (**c**) (*arrows*), and liver metastases (**d**)

PET [4]. Thus, functional imaging should be reserved for patients with increasing CEA levels and otherwise normal diagnostic work-up.

Assessment of distant relapse of CRC

CT-MRI-PET/CT

The liver represents one of the main targets of metastatic spread of CRC [52]. Early detection of limited disease is of particular importance for patient management and outcome. A meta-analysis conducted by Kinkel et al. [53] compared ultrasound (US), CT, MRI, and PET for hepatic metastases from cancers of the gastrointestinal tract. In studies with a specificity higher than 85%, the mean weighted sensitivity for the detection of liver metastases was 55% for US, 72% for CT, 76% for MRI, and 90% for PET. Bipat et al. [54] also performed a meta-analysis to obtain the estimates of sensitivity of CT, MRI, and PET for the detection of colorectal liver metastases. Sensitivity estimates on a per-patient basis for nonhelical CT, helical CT, 1.5-T MRI, and FDG-PET were 60.2%, 64.7%, 75.8%, and 94.6%, respectively. On a per-lesion basis, sensitivity estimates for nonhelical CT, helical CT, 1.0-T MRI, 1.5-T MRI, and FDG-PET were 52.3%, 63.8%, 66.1%, 64.4%, and 75.9%, respectively. For lesions of 1 cm or larger, SPIO-enhanced MRI has turned out to be the most accurate modality.

Whole-body MRI

Parallel imaging (PAT), multiple phased-array surface coils and receiver channels (e.g., total imaging matrix, Tim, Siemens Medical Solutions, Erlangen) opened the door for whole-body (WB) MRI with highly resolved spin echo and/or gradient echo sequences in acceptable imaging time. Compared with CT or PET/CT, total-body MRI seems to be more sensitive for brain, liver, and bone metastases but still offers lower sensitivity for lung metastases, although detectability is strongly related to lesion size and sequences performed. In the meantime, comparable sensitivities for nodules above 4 mm were found [33]. Schmidt et al. [55] compared whole-body MRI with PET/CT in a study including 41 patients with malignant disease. PET/CT detected seven of seven tumors (sensitivity/specificity: 100%/100%), whereas WB-MRI diagnosed six of the seven tumors (sensitivity/specificity: 86%/100%). A total of 60 metastatic lymph nodes were diagnosed with a sensitivity of 98% for PET/CT and 80% for WB-MRI. The median size of malignant nodes was 15± 8 mm for PET/CT and 18±8 mm for WB-MRI. PET/CT found more lymph nodes of all size groups and was superior to WB-MRI in small-sized nodes. Performing PET/CT distant metastases were detected with a sensitivity and a specificty of 82%. WB-MRI had a diagnostic senitivity of 96% and a specificity of 82%. Regarding TNM stage, reliable assessment was possible with each modality (diagnostic accuracy of PET/CT 96% and of WB-MRI 91%).

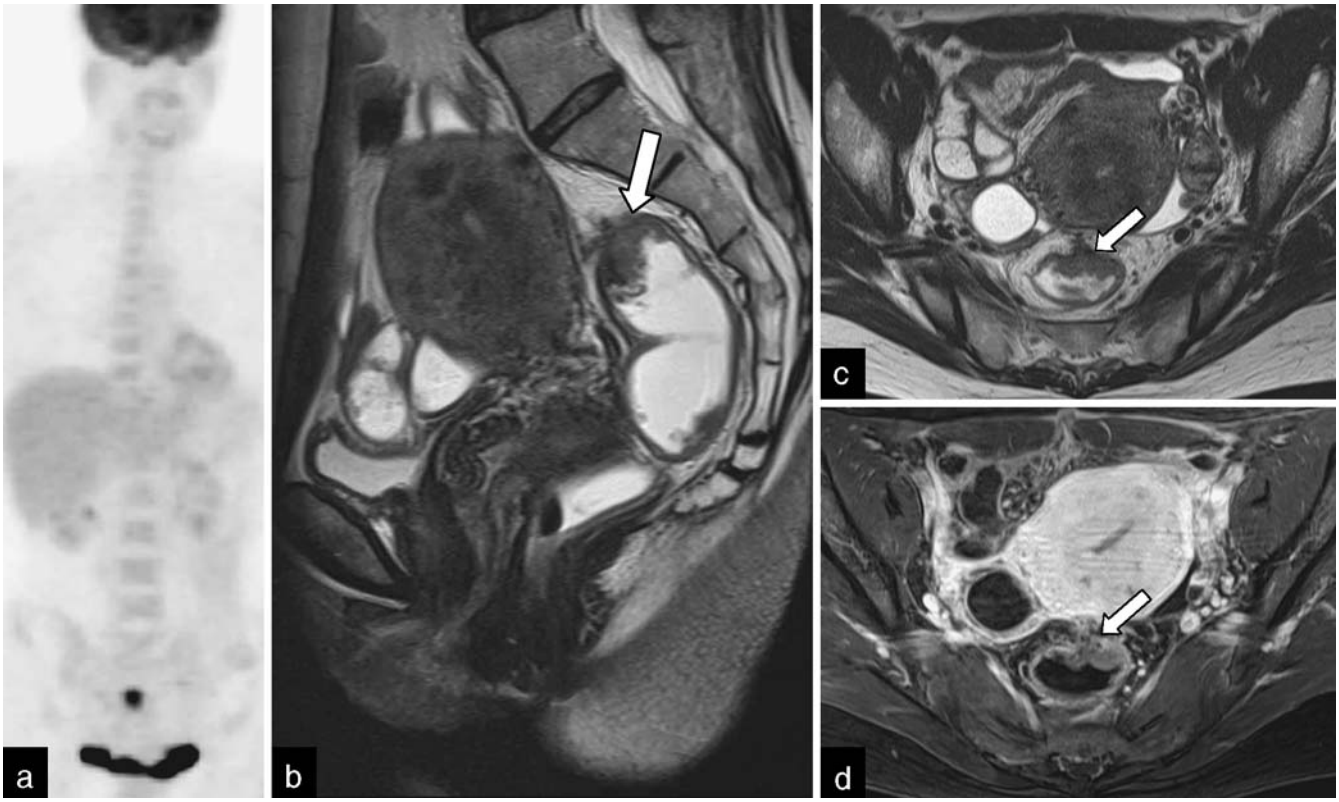

Fig. 7a–d Staging of a female 3 months following tumor perforation of the sigmoid and Hartmann procedure. **a** PET image shows a focal FDG uptake in the presacral area, suggesting residual tumor. The corresponding MRI confirmed the diagnosis (**b**, **c**, **d**). **b** The sagittal T2-weighted TSE, **c** the para-axial T2-TSE, and **d** contrast-enhanced VIBE images demonstrate recurrence in the rectal stump already invading the surrounding scar (*arrows*)

Future perspectives

Sliding multislice for moving-table MRI

Besides endorectal US, pelvic MRI represents the current "gold standard" of primary local staging of rectal cancer. MRI is known to be the most powerful tool in predicting the circumferential resection margin (CRM) [56–62]. For pre- and postoperative work-up of rectal cancer patients, pelvic MRI was routinely combined with abdominal and thoracic CT at our institution. Although MRI of the upper abdomen is an alternative to CT, its combination with high-resolution pelvic MRI during one examination is time-consuming and normally requires patient repositioning. Considering work-flow and cost-effectiveness, an integrated one-stop examination for both local staging and screening for distant metastases would be desirable. In 2006, sliding multislice (SMS) was introduced by Fautz and Kannengiesser [63] as a novel technique for moving-table acquisition [64], allowing seamless coverage of an extended field of view in the axial direction beyond the scanner's available scan region. The idea of SMS is to acquire all slices along the same spatial trajectory relative to the scanner, and the same phase-encoding trajectory is applied during the acquisition. The full *k*-space data of any slice is collected while the slice moves through the scanner from one scan position to the next (move during scan, MDS). The simultaneous acquisition of multiple slices is achieved by shifting the acquisition trajectories of different slices in time. SMS, recently introduced as TimCT (Siemens Medical Solutions, Erlangen, Germany), can be applied to both single-shot and multi-shot sequences [65]. Due to its high image quality and relatively short acquisition times it appeared reasonable to combine SMS with pelvic MRI for follow-up of rectal cancer patients.

Our current imaging protocol for follow-up of rectal cancer patients consists of a T2-TSE sequence (TR/TE 4,960/126, slice thickness 5 mm, FOV 280, flip angle 150°, voxel size 1.0×0.5×5.0) in the sagittal plane after rectal water filling (200 ml) and i.v. butylscopolamine (Buscopan, Boehringer Ingelheim, Germany) injection. Subsequently, a para-axial T2-TSE sequence (TR/TE 4,970/126, slice thickness 4 mm, FOV 250, flip angle 150°, voxel size 1.0×0.5×4.0) is obtained. For TimCT, we routinely combine a standard axial T1-weighted fat-saturated contrast-enhanced FLASH-2D sequence with an axial TIRM sequence. Images are acquired with a table speed of 10 mm/s. The sequence parameters are summarized in

Table 4 Sequence parameters of TimCT-MRI

	TimCT-FLASH-2D	TimCT-TIRM
TR	102 ms	3,568 ms
TE	2.03 ms	101.22 ms
Slice thickness	5.0 mm	6.0 mm
Matrix	320×224	320×200
Pixel bandwidth	300 Hz/pixel	445 Hz/pixel
Flip angle	70°	60°
Slices/package	17	8
Measurements	5	16
Pixel size	1.4×1.1×5.0	1.6×1.1×6.0
Parallel imaging	GRAPPA, factor 2	

Table 4. With a delay of 60 s after i.v. injection of 20 ml Gd-BOPTA (MultiHance, ALTANA Pharma, Konstanz, Germany) the TimCT-FLASH sequence is started. The patients are instructed to hold their breath at the beginning of the measurement and are told to continue breathing 20 s later while the acquisition is completed. During continuous table movement at a speed of 10 mm/s the whole liver can be imaged artefact-free. Comparable with a standard abdominal helical CT, imaging takes place in a portal dominant phase to detect liver metastases from colorectal origin. Within a total acquisition time of 1 min, imaging from the diaphragm to the pelvis is feasible. The free-breathing TimCT-TIRM sequence is acquired to get an overview of the lungs, whole abdomen and pelvis for the detection of pulmonary metastases, malignant lymph nodes and bone marrow infiltration. The imaging protocol is finished by an axial contrast-enhanced 3D-VIBE sequence (TR/TE 8.3/3.2, slice thickness 2 mm, FOV 250, flip angle 25°, voxel size 1.0×0.5×2.0). Noteworthy, the total examination time does not exceed 20 min. Our experiences with TimCT for staging of rectal cancer patients are promising. Unpublished data confirm that the image quality is comparable with a stationary upper abdomen protocol. Moreover, no statistically significant differences in lesion detectability were found between TimCT and MSCT regarding liver metastases and malignant lymph nodes (Fig. 8a–d).

Conclusion

On the one hand, CT, MRI and PET/CT [8, 25, 50] have proven to be accurate in the staging of recurrent rectal cancer. On the other hand, a debate exists on which imaging procedure should be part of an evidence-based surveillance program. We believe that the potential of diagnostic imaging for staging of recurrent rectal cancer patients is underestimated by the current surveillance policy, which is mainly based on data from studies conducted between 1983 and 1996 [16–21]. To elucidate the role of radiologic imaging, there is a need for large, well-designed, clinical trials comparing MSCT, MRI, and

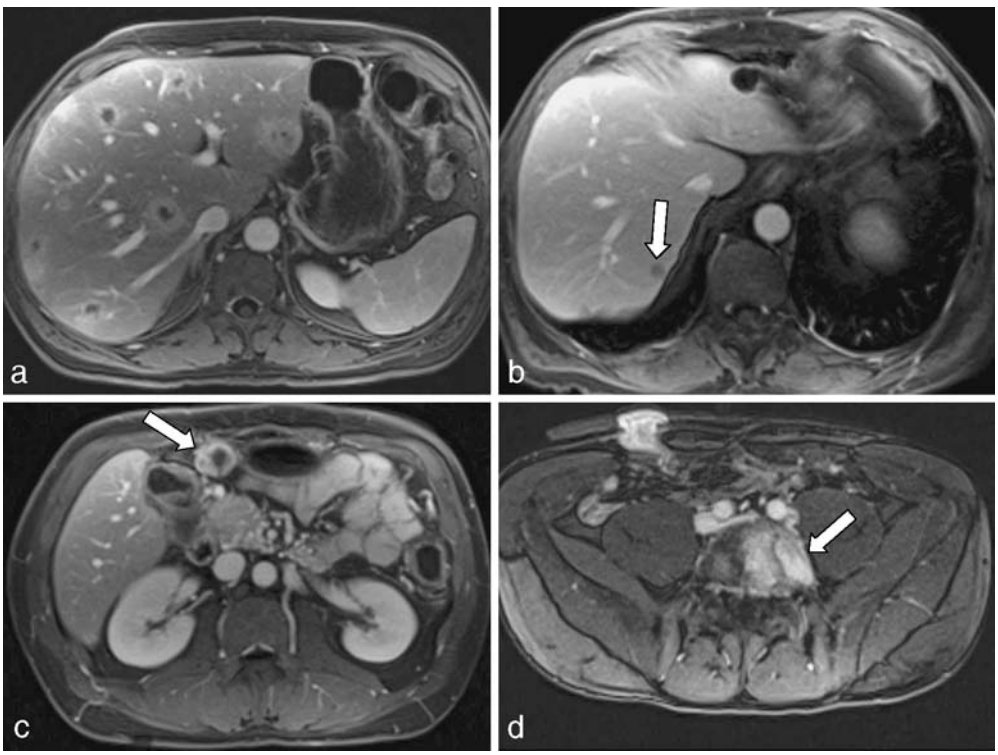

Fig. 8 State-of-the-art contrast-enhanced TimCT-FLASH images acquired during moving-table based abdominal staging of rectal cancer patients. **a** Multiple colorectal liver metastases can be detected during portal-dominant phase in this example. **b** Another example of a small volume liver metastasis (*arrow*) confirmed by surgery. **c** The TimCT-FLASH image shows a lymph node metastasis in the transverse mesocolon (*arrow*). **d** Bone metastasis in the fifth lumbar vertebra is detectable in a patient with recurrent rectal cancer (*arrow*)

PET/CT to better define the optimal postoperative surveillance strategy for CRC patients. Current surveillance practice is heterogenous and expensive [4, 66]. To overcome these drawbacks one option may be risk-adapted follow-up. Also, technical advancements like TimCT-MRI may contribute to improved early detection of relapse and may have the potential to substitute step-by-step or multimodality approaches.

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