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MRI diagnosis and staging of rectal carcinoma

W. Pegios,[1] Th. J. Vogl,[1] M. G. Mack,[1] M. Hünerbein,[3] H. Hintze,[2] J. O. Balzer,[1] H. Lobeck,[4] P. Wust,[1] P. Schlag,[3] R. Felix[1]

[1]Department of Radiology, Humboldt University of Berlin, Virchow Hospital, Augustenburger Platz 1, 13353 Berlin, Germany
[2]Department of Internal Medicine, Humboldt University of Berlin, Virchow Hospital, Augustenburger Platz 1, 13353 Berlin, Germany
[3]Department of Surgery, Humboldt University of Berlin, Virchow Hospital, Augustenburger Platz 1, 13353 Berlin, Germany
[4]Department of Pathology, Humboldt University of Berlin, Virchow Hospital, Augustenburger Platz 1, 13353 Berlin, Germany

Carcinoma of the rectum is one of the common malignant lesions in the United States [1]. Dietary factors, family history, a variety of polyposis syndromes, and longstanding inflammatory bowel disease are risk factors for the development of colorectal carcinoma.

Because specific treatment options vary with tumor location, the preoperative evaluation of rectal carcinoma is important for planning therapy and the assessment of the prognosis. So far, there are several limitations in determining the infiltration of the wall layers in rectal tumors (adenoma and carcinoma) in width and depth by the usually applied endoscopic and X-ray procedures (barium enema examination and computed tomography endosonography, and conventional magnetic resonance imaging (MRI).

Staging with computed tomography (CT) is accurate within the range of 48–74% [2]. Early studies using MRI showed no increase in accuracy over CT [3]. In particular, initial studies demonstrated that the depiction of tumor infiltration at MRI through the bowel wall was difficult. Transrectal ultrasound (US) is now an established imaging modality for the evaluation of the integrity of the wall layers in colorectal lesions [4]. Overstaging seems the most frequent error, both in staging of rectal cancer [5] and screening of adenomas for infiltrating malignancy [6].

MRI is helpful for tumor staging and the detection of tumor recurrence, particularly in clarifying remaining questions after endoscopic diagnosis. It is necessary to minimize the movement of the patient to improve image quality. Especially the use of rapid scanning techniques, endoluminal surface coils, and paramagnetic contrast agents are expanding the applications of MRI in the evaluation of rectal and perirectal disease.

Correspondence to: W. Pegios

We report on our experience using high-resolution endorectal surface coil MRI to evaluate rectal carcinomas and rectal adenomas in a variety of clinical applications. In a prospective study, we compare the results of high-resolution MRI and histopathology.

Materials and Methods

Conventional and endorectal contrast-enhanced MRI of the rectum was performed in volunteers and patients by using a supraconducting MR unit (1.5 Tesla Magnetom SP 63, Siemens, Erlangen, Germany). In 10 healthy volunteers (five male, five female), the normal topographical details of the rectum with its different layers and the adjacent tissues was evaluated. Twenty-nine patients (male/female: 14/15; mean age = 61.7 years old, range = 36–80 years) underwent an extensive clinical examination protocol including endoscopy and a barium enema study before MRI. Two different types of endorectal surface coils (Medrad, Pittsburgh, PA, USA) were used. A prostate endorectal surface coil was used and in eight patients, a colon endorectal surface coil was used in 21 patients. Before placement of the endorectal surface coil, a digital examination of the rectum was performed to make sure that there were no obstructions within the lumen. The distance from the rectal lesion to the anus was determined previously at barium enema examination and endoscopy. The center of the coil was positioned at the center of the lesion. With the prostate coil, the balloon was filled with 60 cm^3 of air; with the colon endorectal coil, no filling of the balloon was necessary. The position of the coil was controlled in the supine position of the patients with a sagittal localizer. With the body coil, the sequence protocol started with a T2-weighted spin-echo (SE) sequence (TR/TE = 2500/22–90, field of view = 350 mm, imaging matrix = 192 × 256, slice thickness = 4 mm, no gap). All endorectal surface coil images were obtained with a 160-mm field of view, 4-mm slice thickness, and an imaging matrix of 192 × 256 to achieve an optimal spatial resolution. T2- (TR/TE = 2500/22–90) and T1- (TR/TE = 700/15) weighted SE precontrast sequences were peformed. For comparative evaluation, 21 patients received an additional Turbo SE sequence TSE (TR/TE = 3700/90). At the slice position with the visually largest tumor extension, dynamic MRI was performed by using a TurboFLASH sequence (TR/TE/TI = 7/3/300, flip angle = 15°) and starting with a bolus of 0.1 mmol/kg b.w. Gd-DTPA (Schering, Berlin, Germany) to evaluate the dynamic contrast enhancement. This sequence, with an acquisition time of 2 s, was re-

Table 1. Study protocols[a]

Coil	Sequence	TR/TE	FOV	SD	Matrix	Plane
Protocol 1: plain imaging						
Body	T2 SE	2500/22-90	350	4	256 × 512	Transverse
EC	T2 SE	2500/22-90	160	4	160 × 512	Transverse
	T SE	3700/90	160	4	192 × 256	Transverse
	T1 SE	700/15	1180	4	180 × 512	Transverse
Protocol 2: dynamic imaging and Gd-DTPA (0.1 mmol/kg b.w.)						
EC	Turbo/FLASH	7/3	160	1	128 × 128	Transverse
	T1 SE	700/15	180	4	180 × 512	Transverse
	T1 SE	700/15	180	4	180 × 512	Sagittal

[a] FOV, field of view; SE, spin echo

peatedly started with a delay of 2 s. Thereafter, axial and sagittal T1-weighted sequences were peformed (Table 1). The total examination time including placement of the coil took 60–75 min.

Qualitative and Quantitative Evaluation

All images of patients and volunteers were evaluated separately by a panel of three radiologists by using a four-point rating scale (1 = excellently distinguishable, 2 = well distinguishable, 3 = poorly distinguishable, 4 = not distinguishable) for evaluating the layers of the rectal wall and the perirectal tissue. The lesions were staged according to the TNM staging system (Table 2). The radiologists read the images with knowledge of the clinical information but without knowledge of the results of other examinations (endoscopy, CT, and endosonography). The quantitative evaluation was performed by using a region-of-interest (ROI) technique.

The preoperatively posted staging of the lesions were compared with the results of intraoperative inspection and histology after resection or electrolaser resection in all cases (n = 17 rectal carcinomas and n = 12 rectal adenoma).

Histopathology was obtained via biopsy (n = 10) and operative resection (n = 19). Tubulovillous adenomas were proven with epithelial dysplasia grade II in six patients, grade II–III in four, and tubulovillous adenoma grade III with beginning carcinoma in situ in two. Five patients presented a rectal carcinoma stage pT1, six presented stage pT2, four presented stage pT3, and two presented stage pT4.

Table 2. TNM staging for cancer of the colon and rectum[a]

Stage	Level of involvement
Tumor	
Tx	Tumor cannot be assessed
To	No evidence of tumor
Tis	Carcinoma in situ[b]
T1	Tumor invades the submucosa
T2	Tumor invades the muscularis propria
T3	Tumor invades trough the muscular is propia into the subserosa or into nonperitonealized pericolic or perirectal tissues
T4	Tumor invades other organs or structures
Nodes	
Nx	Regional lymph nodes cannot be assessed
No	No involved lymph nodes
N1	Fewer than four regional nodes positive for tumor
N2	More than four regional nodes positive for tumor
N3	Central nodes positive for tumor
Metastasis	
Mx	Presence of distant metastasis cannot be assessed
Mo	No distant metastasis
M1	Distant metastasis

[a] From the American Joint Committee on Cancer (AJCC). Manual for staging of cancer, 4th ed. Philadelphia: JB Lippincott, 1992
[b] Cancer cells within the basement membrane or lamina propria with no extension through the muscularis propia into the submucosa

Results

Normal Findings

The zonal anatomy of the rectal wall is best appreciated in transverse-plane images. The evaluation of the perirectal space is also easily accomplished in the transverse plane. Plain MRI with the body coil demonstrates a high soft tissue contrast of adjacent structures and allows the differentiation of the mucosa as a band with high signal intensity in the T2-weighted sequence surrounded by a layer of low signal intensity related to the muscularis propria. When the rectum is imaged after intravenous administration of Gd-DTPA, the enhancement of the submucosa and mucosa allows visual differentiation of the layers of the rectal wall on T1-weighted scans. A further differentiation of other rectal layers is uncertain.

Plain and contrast-enhanced MRIs with the endorectal surface coil using T2- and T1-weighted sequences allows the identification of all layers of the circumference of the rectal wall (Fig. 1). These layers consist of an inner layer of medium signal intensity (mucus and fluid between the coil and the rectal wall),

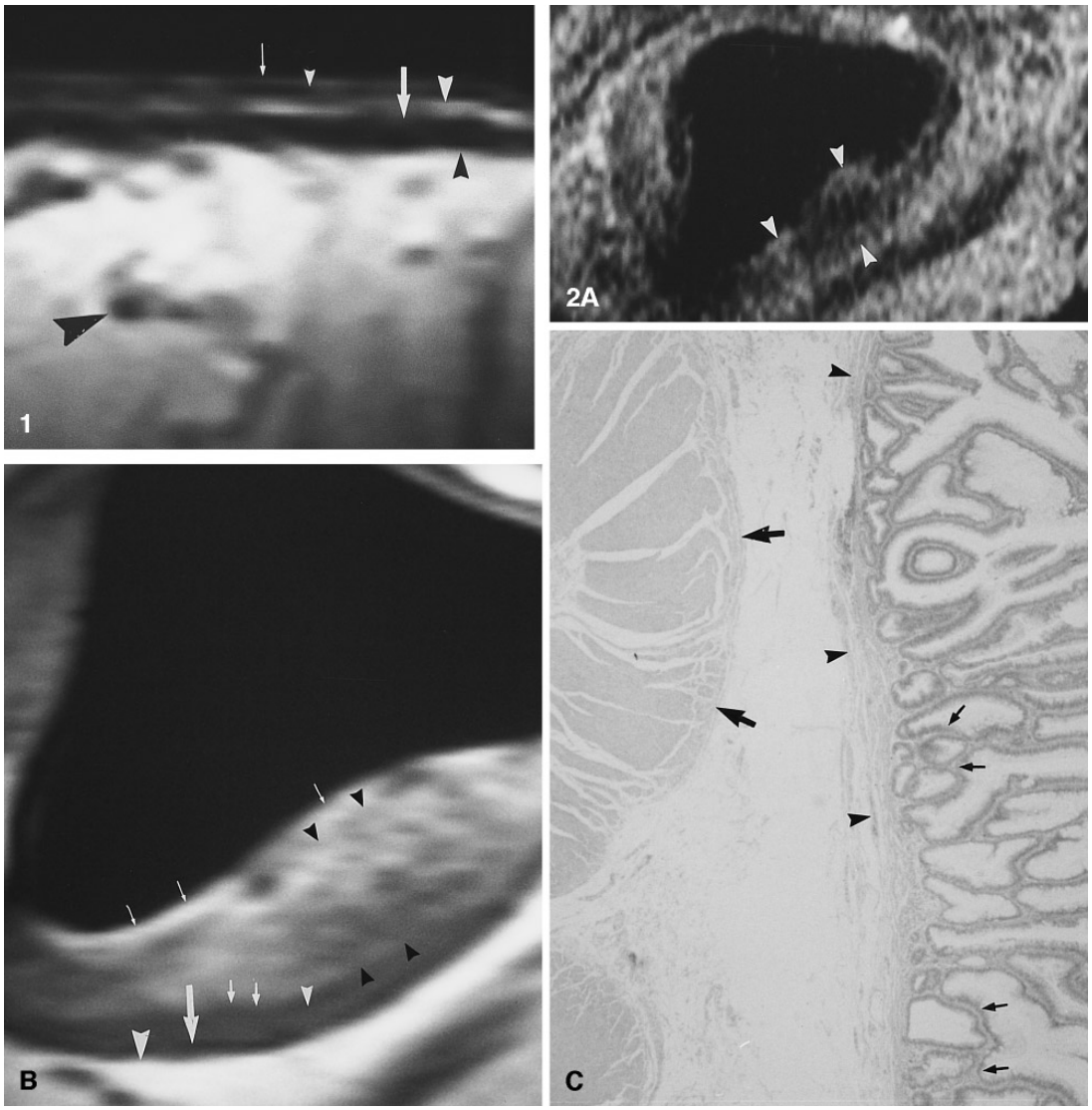


Fig. 1. Endorectal MRI of the normal rectal wall (sagittal T1-weighted SE, 700/15). Note the multiple layers visualized in the rectal wall: high signal intensity mucus within the rectal lumen (*thin white arrow*), low signal intensity mucosal layer (mucosa and muscularis mucosa) (*small white arrowhead*), high signal intensity submucosal layer (*large white arrowhead*), low signal intensity muscularis propria (*white arrow*), and high signal intensity perirectal fat (*small black arrowhead*), vessel (*large black arrowhead*).

Fig. 2. A Axial T2-weighted SE image (TR/TE = 2500/22) with conventional MRI demonstrates an inexact differentiation of a polypoid lesion of the rectum with a low signal intensity (*white arrowheads*). **B** Endorectal MRI (T1-weighted SE, 700/15, after injection of 0.1 mmol/kg b.w. Gd-DTPA) demonstrates a sessile tubulovillous adenoma of the rectum. The different layers of the rectal wall can be identified. From lateral to medial, the high signal intensity of the perirectal fat tissue (*large white arrowhead*), followed by the low signal intensity of the musculars propria (*large white arrow*), followed by a layer of high signal intensity representing the submucosal core (*small white arrowhead*), and the low signal intensity of the muscularis mucosa (*small white arrows*). Note the high signal intensity of the thickened mucosal layer (*black arrowheads*) with mucus within the rectal lumen (*thin white arrows*). **C** Histologic section demonstrates the normal muscularis mucosa (*arrowheads*) and the thickened mucosa with typical dysplasia grade III (*small arrows*), and the muscularis propria (*large arrows*).

a layer of low signal intensity (mucosa and muscularis mucosa), a middle layer of medium-to-high signal intensity (submucosa), a second layer of low signal intensity (muscularis propria), and an outer layer of high signal intensity (perirectal fat) in the T1-weighted sequence. On T2-weighted SE images, the inner layer (mucus and fluid between the coil and the rectal wall) and the middle layer (submucosa) appear with a high signal intensity. All layers of the rectal wall were visible in all patients (n = 29). The multiple layers of the rectal wall were demonstrated in the proximity of rectal tumors in all patients.

Pathologic Findings

By using conventional MRI, rectal carcinomas are demonstrated with high signal intensity in the T2-weighted sequence and are therefore more conspicuous than in T1-weighted images. Infiltration of the bowel wall is best demonstrated in T2-weighted scans because these images optimally show the normal zonal anatomy of the wall and because the contrast between high signal intensity of tumors and low signal intensity of muscle tissue is maximized. The evaluation of perirectal fat and soft tissue infiltration by the tumor is most conspicuous in T1-weighted images. Rectal carcinomas are enhanced after the administration of Gd-DTPA, and Gd-DTPA-enhanced T1-weighted images assist in determining the depth of tumor growth. In general, transverse images are the most useful in evaluating rectal wall invasion and perirectal tumor extension.

All patients tolerated endorectal MRI well and without complications. Endorectal MRI enabled correct identification of all layers of the rectal wall and differentiation between the different tumor stages. The correlation between the histopathologic stage and MRI stage is summarized in Tables 3 and 4. The pretherapeutical MRI stage agreed with the staging results from pathology in 25 of 29 (85%) patients. By using endorectal MRI, the extent of invasion was overestimated in four patients and detailed in two patients in whom tubulovillous adenomas were overstaged. One patient with a stage pT1 tumor was staged as T2, and one patient with a pT2 tumor was staged as T3. The rectal lesions were different in shape and size. Lesion size ranged from 2.5 to 6.5, cm and the distance between the lesion and the external sphincter varied from 4 to 10 cm.

Criteria for the diagnosis of an adenoma are the visualization of the intact muscularis mucosa, a clear demarcation of the submucosa, sharp borders of the lesion, and a highly homogeneous contrast enhancement of the lesion in the dynamic sequences. In T2-weighted sequences, the tumors characteristically presented with a homogeneous high signal intensity that was brighter than the surrounding structures. T1-weighted sequences proved optimal for the exact delineation of the lesions versus the different wall layers (Fig. 2).

Two patients with the MR diagnosis of a carcinoma stage T_1 were histopathologically staged as an adenoma with severe cell dysplasia. In both cases, we were retrospectively unable to verify the muscularis mucosa.

The follow-up evaluation in six patients with large tubulovillous adenomas demonstrated the total removal of the tumor after endoscopic electrolaser resection. After therapy, MRI with the endorectal surface coil demonstrated the resection of the mucosa and parts of the submucosa. Again, a clear visualization of the different rectal layers was found. Only T2-weighted and Turbo SE images showed a slight increase of signal intensity and an edematous infiltration of the submucosa at the former localization of the adenoma due to the ongoing repair mechanism (Fig. 3).

Table 3. Comparison of tumor stage at MR imaging and histopathologic examination

	Pathologic examination				
MRI	Adenomas	T1	T2	T3	T4
Adenomas	10	0	0	0	0
T1	2	4	0	0	0
T2	0	1	5	0	0
T3	0	0	1	4	0
T4	0	0	0	0	2

The presence of mucosal thickening with preservation of the submucosal layer is indicative of a stage T_1 lesion (Fig. 4). One patient with MR diagnosis of a rectal carcinoma stage uT_2 was histopathologically staged as a pT_1. This was caused by the thinning of the muscularis propria with compression and nonvisualization of the submucosa (mechanical compression) near the base of the lesion. The retrospective evaluation of the dynamic TurboFLASH sequence demonstrated an intact muscularis propria without suspicious irregularities.

The extension into, but not through, the muscularis propria with high signal intensity in the T2-weighted images in a band of low signal intensity with the associated visualization of a partially intact muscularis propria and contrast enhancement in the T1-weighted images appear to represent valid criteria for diagnosing a stage T_2 lesion. One patient with the MR diagnosis of a rectal carcinoma stage uT_3 was histopathologically staged as a pT_2. This was caused by the irregularity of the border between the muscularis propria and the perirectal fat tissue in the T1-weighted sequence (Fig. 5A–B). However, the retrospective evaluation of the dynamic TurboFLASH and the Turbo SE sequences demonstrated a clear demarcation of the muscularis propria without infiltration into the perirectal fat tissue (Fig. 5C–D). The complete disruption of the muscularis propria and an unsharp border to the perirectal fat tissue are criteria for a T_3 lesion. The tumor was identified by its extension beyond the contour of the rectum wall in all four cases with stage T_3 under gross examination (Fig. 6A–B).

A T_4 lesion is presented with an infiltration of adjacent structures. Two patients with clinical diagnosis of stage T4 were included in this study in the course of hyperthermic treatment protocol. In both cases, the endorectal MRI stage agreed with the staging results from pathology. On the T1-weighted images, the rectal wall demonstrated a relatively homogeneous intermediate signal intensity pattern. These images provided good contrast between the perirectal fat and the bowel wall

Table 4. Statistical evaluation (%) of carcinoma and adenoma of the rectum

	Adenomas (n = 12)	T1 (n = 5)	T2 (n = 6)	T3 (n = 4)	T4 (n = 2)
Sensitivity	83.3	80	83.3	100	100
Specificity	100	100	100	100	100
Positive predictive value	100	100	100	100	100
Negative predictive value	89.5	96	95.8	100	100

and were helpful for identifying perirectal vessels and lymph nodes (Figs. 4B, 6B).

Discussion

Accurate preoperative staging has a definite impact on the surgical management of rectal carcinoma. The standard surgical therapy for rectal cancer is abdominoperineal resection [7]. Because of the morbidity associated with this procedure, the most notable of which are the social and physical problems of a permanent colostomy, a number of alternative surgical approaches have been proposed. These include anus-sparing radical resections, such as low anterior resection [8] and local excision [9], and nonsurgical approaches such as low-kilovoltage endorectal irradiation, electrocautery, and transanal fulguration.

Patient selection is considered essential for obtaining a good outcome in the treatment of early rectal cancer. Carlson et al. [10] reported that prognosis of patients treated for cure with conservative local therapy depends on the extent of the lesion. Consequently, the exact staging of the local extent of rectal cancer is important to the sucessful enforcement of any conservative treatment regime. In addition, the preoperative staging is important in selecting patients for planning an adjuvant preoperative radiation therapy, chemotherapy, and hyperthermia therapy. O'Connell et al. [11] reported that preoperative radiation therapy resulted in a better outcome than postoperative radiation therapy in patients with invasive disease. The hyperthermia therapy systems based on radiowave irradiation have been commercially available for regional hyperthermia of the pelvis since the mid-1980s. This technology allows one to perform sufficiently tolerable and effective regional hyperthermia on rectal carcinomas. When used as part of curative preoperative and postoperative multimodal therapeutic stratagies, hyperthermia can lead to improvement in local control.

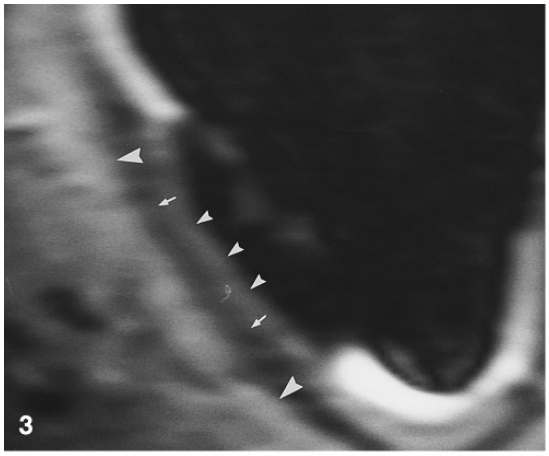
For years, the mainstay of local staging of rectal cancer has been the digital rectal examination. The accuracy of the digital rectal examination in correctly staging rectal cancer has been reported to be approximately 70–75% [12].

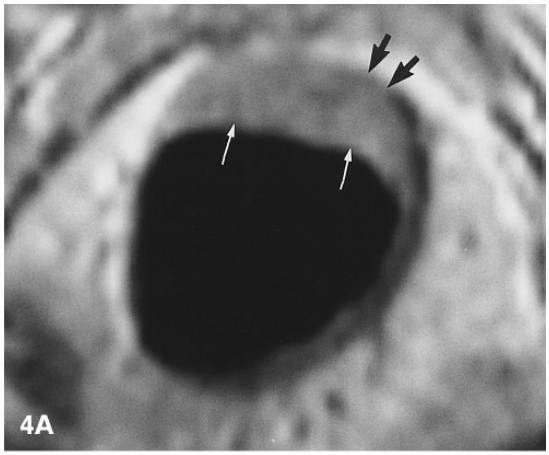
Radiological modalities that have been used in the staging of rectal carcinoma include CT, transrectal US and MRI. The accuracy of staging with CT was reported to be as high as 92% in initial reports [13]. Later articles showed that CT studies have limited usefulness for enabling accurate staging of local disease or depth of wall invasion [14]. However, CT does not permit evaluation of less extensive tumors because differentiation of the normal layers of the intestinal wall is impossible due to poor soft tissue contrast. A recent study showed the sensitivity and specificity of CT for the detection of extension of perirectal fat to reach [15]. Tumors located low in the rectum were particularly difficult to stage because of the paucity of perirectal fat in this region [14].

Transrectal US is now an established imaging modality for the evaluation of the integrity of the wall layers underneath the colorectal lesion [4]. Some articles reported that transrectal US is 77% accurate in demonstrating invasion of carcinoma into the perirectal fat and 50% accurate in demonstrating perirectal lymph node involvement [15]. Recent articles have reported a 75–83% accuracy for staging rectal cancer with transrectal US [16]. However, transrectal sonography does not provide reliable contrast between the tumor and the muscularis propria. Thus, once the submucosa is breached, it is often diffucult to determine the depth of muscle invasion and to detect early perirectal fat invasion. In addition, the effect of different US criteria on differentiation of T2 and T3 tumors is limited. Spontaneous or iatrogenic inflammation is a major limiting factor [17].

Complete removal of adenomatous polyps is the most important measure in prophylaxis of colorectal adenocarcinomas [18]. Laser photocoagulation is often used in broad-based villous adenomas in patients with a poor surgical or medical condition [19]. Often in follow-up examinations with transrectal sonography, the inflammatory changes in the rectal wall after treatment of colorectal adenoma with photocoagulation may simulate malignant infiltration (generally during the first 6 weeks) [20].

Few articles have been published about the use of MRI with a body coil to stage rectal carcinoma [3, 14]. The depth of bowel wall invasion cannot be determined, and the accuracy of staging with conventional MRI has been reported as being not than higher 60% [14]. The limitation of conventional MRI in the initial studies was the result of inadequate resolution. De Lange et al. [21] described results with an external surface coil for MRI of rectal cancer. They were able to decrease the voxel





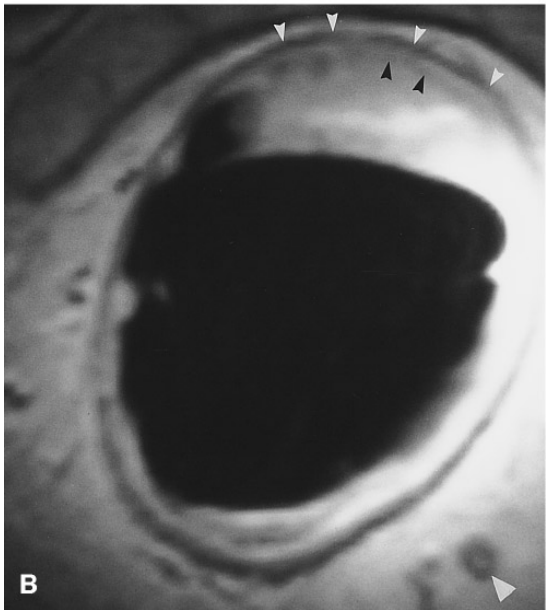


Fig. 3. Eight weeks after electrolaser resection of a sessile tubulovillous adenoma. The endorectal surface coil image demonstrates a clear visualization of the different rectal layers. The Turbo SE image (3700/90), shows a slight increase of signal intensity and an edematous infiltration of the remaining parts of the submucosa (*small arrowheads*), including the muscularis propria (*arrows*) and the perirectal fat (*large arrowheads*).

Fig. 4. A Axial T2-weighted SE image (2500/22) with conventional MRI demonstrates a sessile lesion of the rectum (*white arrows*), with a suspicious extention into the muscularis propria (*black arrows*), which was initially and mistakenly interpreted as a T2 lesion. **B** Endorectal MRI (T2-weighted SE, 2500/22) demonstrates the same lesion of the rectum manifested by focal mucosal thickening with a high signal intensity submucosal core (*black arrowheads*); the muscularis propria (*small white arrowheads*) layer has not been involved. In addition, one small, 3-mm-diameter perirectal lymph node is completely replaced by soft tissue (*large white arrowhead*). This was positive for carcinoma at pathologic examination (stage pT1N1).

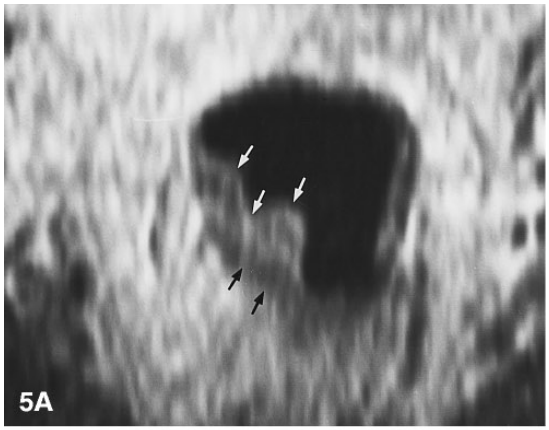
volume to 5.7 mm^3 and reported a high accuracy for identifying lesions invading the perirectal fat (89%). This technique is nonadvantageous in obese patients because the sensitive volume of the surface coil configuration is limited to approximately 1 radius.

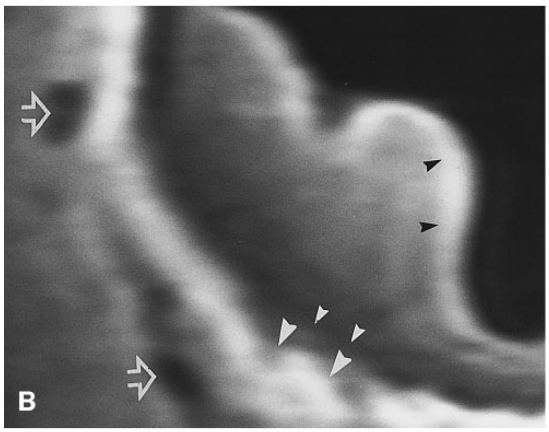
Several investigators have reported the use of a high-resolution endorectal surface coil [22]. Schnall et al. [23] reported an accuracy of 81% in staging the extent of the primary lesion in rectal carcinoma. In addition, his group reported a specificity of 72% for N1 disease in demonstrating perirectal adenopathy. However, there are still some remaining problems in using the endorectal surface coil. It is presumed to be a result of the pressure from the balloon compressing the low signal intensity mucosa and muscularis propria together, thereby making the layers difficult to be identified. This phenomenon is especially problematic in the use of the prostatic coil, whereas these artifacts could be reduced with the rectal coil.

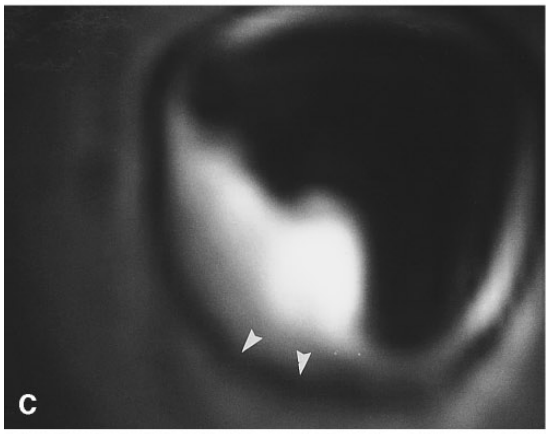
Our results demonstrate that endorectal MRI can be useful for staging rectal tumors. The layers of the rectal wall are visible in all cases. It is important that none of the cases were understaged. Such accuracy could spare patients with highly invasive disease from being undertreated. The accuracy of 85% in staging the extent of a primary lesion with MRI is better than that reported for CT and body coil MRI and similar to that claimed for endorectal sonography.

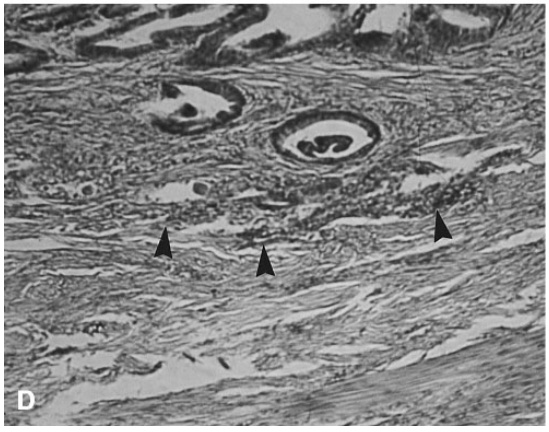
The follow-up examinations have demonstrated that endorectal surface coil MRI is probably improving the follow-up studies after electrolaser resection in comparison with transrectal US. This is due to the misinterpretation of inflammatory changes when using transrectal US.

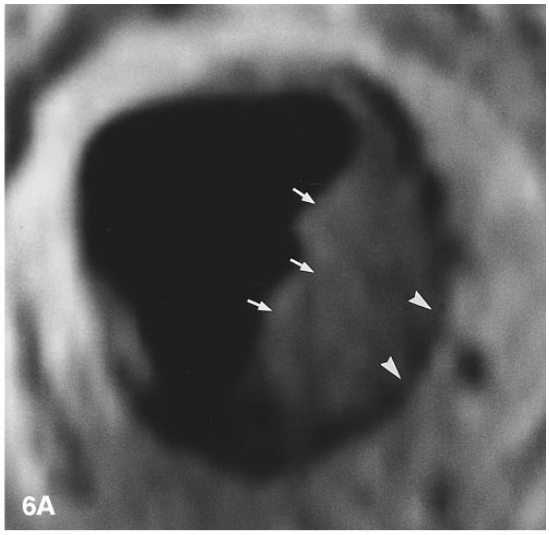
However, high-resolution endorectal MRI was excellent for depicting perirectal nodes as small as 3 mm in diameter, but inflammatory nodes could not be differentiated from metastatic nodes on the basis of size











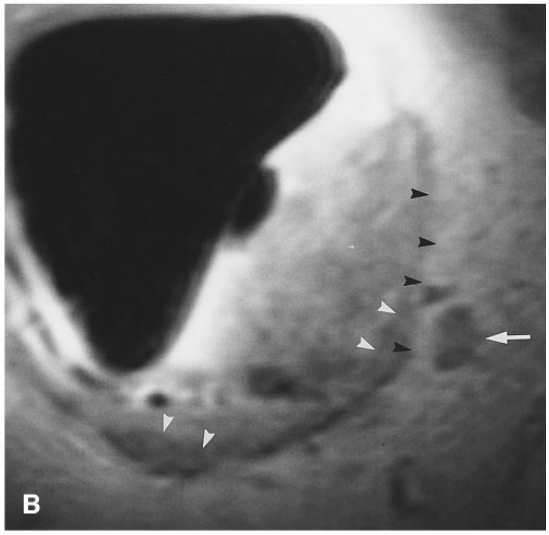


Fig. 5. A Axial T2-weighted SE image (TR/TE = 2500/22) with conventional MRI shows a polypoid lesion (*white arrows*) of the rectum with imprecise differentiation between the muscularis propria and the perirectal fat (*black arrows*). This limitation is a result of inadequate spatial resolution. **B** Endorectal MRI (T1-weighted SE, 700/15) of the same patient demonstrates a polypoid rectal cancer manifested by focal mucosal thickening with high signal intensity (*black arrowheads*). In addition, an area with suspicious disruption of the muscularis propria (*small white arrowheads*) and irregular extention into the perirectal fat (*large white arrowheads*), which was initially mistakenly interpreted as stage T3. *Open white arrows*, vessels. **C** Dynamic TurboFLASH sequence (TR/TE = 7.5/3, after injection of 0.1 mmol/kg b.w. Gd-DTPA) obtained from the patient shown in B demonstrates a depressed lesion, complete disruption of the submucosa with involved, but not disrupted, muscularis propria (*arrowheads*) (stage pT2). **D** Histopathology results with hematoxylin-eosin demonstrate tumor invanding into, but not through, the muscularis propria (*arrowheads*).

Fig. 6. A Axial T2-weighted SE image (2500/22) with conventional MRI demonstrates a polypoid lesion (*arrows*) of the rectum with an uncertain involvement of the perirectal fat (*arrowheads*). **B** Endorectal MRI (T1-weighted SE, 700/15, after injection of 0.1 mmol/kg b.w. Gd-DTPA) of the same patient demonstrates the inhomogeneous mucosal thickening of a rectal cancer that is completely disrupting the submucosa (*white arrowheads*) and the muscularis propria (*black arrowheads*), indicating a stage T3. In addition, one 5-mm-diameter perirectal lymph node (*white arrow*) was positive for carcinoma at pathologic examination (stage pT3N2).

or signal intensity. T1-weighted sequences provided excellent contrast between the perirectal fat and the bowel wall and were helpful for identifying perirectal lymph nodes. Further study of node architecture, geometry, and contrast-enhancement characteristics, especially in the use of dynamic sequences, may improve our ability to distinguish between malignant and reactive nodes.

Our results are promising for the use of high-resolution endorectal surface coil MRI in the preoperative stage and for the evaluation of rectal lesions. Additional studies are necessary to establish additional criteria for interpreting the high-resolution rectal images.

References

1. Boring CC, Squires TS, Tong T. Cancer statistics 1991. *CA* 1991;41:119–151
2. Moss AA. Imaging of colorectal carcinoma. *Radiology* 1989; 170:308–310
3. Butch RJ, Stark DD, Wittenberg J. Staging rectal cancery by MR and CT. *AJR* 1986;146:1155–1160
4. Rifkin MD, Marks GJ. Transrectal US as an adjunct in the diagnosis of rectal and extrarectal tumors. *Radiology* 1985;157:499–502
5. Tio TL, Coene PPLO, van Delden OM, et al. Colorectal carcinoma: properative TNM classification with endosonography. *Radiology* 1991;179:165–170
6. Hulsmans FJH, Tio TL, Mathus-Vliegen EMH, et al. Colorectal villous adenoma: transrectal US in screening for invasive malignancy. *Radiology* 1992;185:193–196
7. Curley SA, Roh MS, Rich TA. Surgical therapy of early rectal carcinoma. *Hematol Oncol Clin North Am* 1989;3:87–101
8. Rothenberger DA, Wong WD. Rectal cancer: adequacy of surgical management. *Ann Surg* 1985;17:309–312
9. Hager TH, Gall FP, Hermanek P. Local excision of cancer of the rectum. *Dis Colon Rectum* 1983;26:149–151
10. Carlson CA, Fabris G, Arslan-Pagnini C, et al. Prognostic correlations of operable carcinoma of the rectum. *Dis Colon Rectum* 1985;28:47–50
11. O'Connell MJ, Gunderson LL, Fleming TR. Adjuvant therapy of rectal cancer. *Semin Oncol* 1988;15:138–145
12. Hildebrandt U, Feifel G. Preoperative staging of rectal cancery by intrarectal ultrasound. *Dis Colon Rectum* 1985;28:42–46
13. Thoeni R, Moss AA, Schnyder P, et al. Detection and staging of primary rectal and rectosigmoid cancer by computed tomography. *Radiology* 1981;141:135–138
14. Hodgman CG, MacCarty RL, Wolf BG, et al. Preoperative staging of rectal carcinoma by computed tomography and 0.15T magnetic resonance imaging. *Dis Colon Rectum* 1986;29:446–450
15. Rifkin MD, Ehrlich SM, Marks G. Staging of rectal carcinoma: prospective comparison of endorectal US and CT. *Radiology* 1989;170:319–322
16. Milsom JW, Graffner H. Intrarectal ultrasonography in rectal cancer staging and in the evaluation of pelvic disease: clinical uses of intrarectal ultrasound. *Ann Surg* 1990;212:602–606
17. Hulsmans FJH, Tio TL, Fockens P, et al. Assessment of tumor infiltration depth in rectal cancer with transrectal sonography: caution is necessary. *Radiology* 1994;190:715–720
18. Shinya H, Wolff W. Morphology, anatomic distribution and cancer potential of colonic polyps: an analysis of 7,000 polyps endoscopically removed. *Ann Surg* 1979;190:679–683
19. Mathus-Vliegen EMH, Tytgat GNJ. Nd:YAG laser photocoagulation in colorectal adenomas: evaluation of its safety, usefulness and efficacy. *Gastroenterology* 1986;90:1865–1873
20. Hulsmans FJH, Mathus-Vliegen EMH, Bosman S, et al. Colorectal adenomas: inflamatory changes that simulate malignancy after laser coagulation-evaluation with transrectal US. *Radiology* 1993; 187:367–371
21. de Lange EE, Fechner RE, Edge SB, et al. Preoperative staging of rectal carcinoma with MR imaging: surgical and histopathologic correlation. *Radiology* 1990;176:623–628
22. Chan TW, Kressel HY, Milestone B, et al. Rectal carcinoma: staging at MR imaging with endorectal surface coil—work in progress. *Radiology* 1991;181:461–467
23. Schnall MD, Furth EE, Rosato EF, et al. Rectal tumor stage: correlation of endorectal MR imaging and pathologic findings. *Radiology* 1994;190:709–714