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The importance of MRI for rectal cancer evaluation

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Abstract

Magnetic resonance imaging (MRI) has gained increasing importance in the management of rectal cancer over the last two decades. The role of MRI in patients with rectal cancer has expanded beyond the tumor-node-metastasis (TNM) system in both staging and restaging scenarios and has contributed to identifying “high” and “low” risk features that can be used to tailor and personalize patient treatment; for instance, selecting the patients for neoadjuvant chemoradiation (NCRT) before the total mesorectal excision (TME) surgery based on risk of recurrence. Among those features, the status of the circumferential resection margin (CRM), extramural vascular invasion (EMVI), and tumor deposits (TD) have stood out. Moreover, MRI also has played a role in surgical planning, especially when the tumor is located in the low rectum, when the relationship between tumor and the anal canal is important to choose the best surgical approach, and in cases of locally advanced or recurrent tumors invading adjacent pelvic organs that may require more complex surgeries such as pelvic exenteration. As approaches using organ preservation emerge, including transanal local excision and “watch-and-wait”, MRI may help in the patient selection for those treatments, follow up, and detection of tumor regrowth. Additionally, potential MRI-based prognostic and predictive biomarkers, such as quantitative and semi-quantitative metrics derived from functional sequences like DWI and DCE and radiomics, are under investigation. This review provides an overview of the current role of MRI in rectal cancer in staging and restaging and highlights the main areas under investigation and future perspectives.

Keywords

Magnetic resonance imaging; Rectal cancer

1. Introduction

Colorectal cancer is the third most common cancer and the second leading cause of death due to cancer in the world. Rectal cancer accounts for approximately one-third of these

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cases [1]. Magnetic resonance imaging (MRI) is the modality of choice for local staging and restaging due to its superb soft-tissue resolution. It also plays an essential role in evaluation of treatment response, surveillance and in detection of local recurrence after surgery.

Clinical assessment by digital rectal examination (DRE), endorectal ultrasound (ERUS), and computerized tomography (CT) were the first methods used for preoperative assessment in rectal cancer. However, DRE is limited by its subjective nature and inevitably understages extramural disease and mesorectal fascia involvement. ERUS is also highly operator-dependent and limited for proximal and stenotic rectal tumors, disease beyond the immediate lumen and for evaluation of the mesorectal fascia [2, 3]. CT lacks the inherent soft tissue resolution for discriminating rectal wall layers and involvement of the pelvic floor structures and its use is confined to determining the presence of distant metastases [4–6].

MRI technological improvements during the last two decades have enhanced our understanding of the detailed anatomy of the rectum and surrounding structures to allow accurate local staging essential to patient care. MRI has also advanced our knowledge of new prognostic imaging features such as extramural vascular invasion (EMVI), tumor deposits (TD) and tumor mucinous content [7–9]. Advances in functional MRI techniques which interrogate the tumor environment (e.g., diffusion weighted images (DWI)) may in the future play a role however, more research is needed to validate their prognostic utility.

In recognition of these rapid advances in our knowledge base, training sessions and hands-on workshops (e.g. offered by the American College of Radiology (ACR) [10] and the UK Professor Gina Brown [11]) are more frequently held and are essential tools in knowledge propagation given the proven learning curves among radiologists and trainees.

2. A Primer on Rectal Cancer Treatment

The goals of modern management of rectal cancer are to reduce perioperative and long-term morbidity, preserve organ function and quality of life, and minimize the risk of local recurrence and distant metastases.

Rectal cancer management has changed rapidly over the past decades and is more driven by imaging today. Until the early 1980s, patients were primarily treated with non-anatomic plane surgery alone, which resulted in a high risk of pelvic recurrence, morbidity, and mortality. Surgery was then supplemented with adjuvant therapy soon after numerous studies showed that postoperative chemoradiotherapy reduced pelvic recurrence rates and enhanced survival [12, 13]. In parallel, the importance of the surgical technique as demonstrated by Heald in the UK [14] and Enker in the USA [15] completely changed the landscape and demonstrated the superiority of total mesorectal excision (TME) (radical excision of the rectum and mesorectal envelope en bloc) over the non-anatomic perivisceral procedure being done at the time [14]. Later, the German Rectal Cancer Study found that preoperative chemoradiotherapy, as opposed to postoperative chemoradiotherapy, resulted in better pelvic control and sphincter preservation, and decreased morbidity [16], establishing yet a new standard of care.

MRI in parallel with histopathology has contributed to our knowledge of the prognostic inhomogeneity of T3 rectal cancers and has challenged the empiric neoadjuvant chemoradiation treatment paradigm often used irrespective of T3 depth [17]. Tumors extending ≤ 5mm beyond the muscularis propria have local recurrence and survival rates similar to T2 tumors. As such, European guidelines advise treatment of early rectal tumors ≤ T3b without clear involvement of the MRF with TME surgery alone, while locally advanced tumors ≥ T3c, with involved CRM on MRI (≤ 1mm), or presence of EMVI, are treated with neoadjuvant chemoradiotherapy (NCRT) followed TME surgery [18]. The empiric administration of preoperative radiotherapy (RT) to all patients with imaging suspicion for lymph node metastases is also still debatable [19], and the results of the PROSPECT trial testing *selective* use of RT are eagerly awaited [20].

As with other cancers, there is a growing interest in developing more patient-tailored approaches in recognition of the multiple (and increasing) risk factors/biomarkers that identify patients with “good prognosis” versus “bad prognosis” rectal tumors. The Quicksilver study, a prospective multicenter study whose primary endpoint was evaluating the safety and feasibility of MRI selected “good prognosis” patients (≤ T3b, distance to the mesorectal fascia greater than 1 mm from the primary tumor, discontinuous tumor nodule, or suspicious lymph node, and absent or equivocal EMVI) to undergo primary surgery, found low rates of positive circumferential resection margins (CRM), the known strongest predictor of local recurrence [21]

Another treatment paradigm gaining traction is avoidance of radical surgery altogether in selected candidates with excellent responses. It is well established that pathologic complete response (pCR) rates of up to 20% or higher have been observed after neoadjuvant chemoradiation [22]. A nonoperative management approach (also called “watch-and-wait” or organ-sparing) or perhaps local excision may be proven acceptable in this scenario, but because of limited long-term results and the lack of a reliable way to accurately identify these patients preoperatively, it is premature to make conclusions. The only prospective trial testing the non-operative management paradigm, the OPRA study, has finished accrual and long-term outcome results are eagerly awaited [23].

Among the rapidly evolving concepts of risk factors impacting treatment, lateral pelvic lymph nodes [primarily obturator and internal iliac] are approached very differently in Japan than in most western treatment centers. Routine dissection of these nodes has been historically recommended by Japanese societies for tumors located below the peritoneal reflection (generally 0–8 cm) to lower the risk of pelvic recurrence. This is not routinely recommended by European and American societies [17, 19]. Although it has been shown that selective lateral lymph node dissection may reduce local recurrence, no significant impact on overall survival can be demonstrated [24–27].

3. What We’ve Learned Through the Implementation of MRI into National Clinical Trials and the Impact of MRI on the Health Care System

The use of pelvic MRI for rectal cancer evaluation and management, in part, derives from its incorporation into clinical trials testing new treatments. This has been either in the

form of (i) MRI-based risk categories *determining* treatment pathways (in concert with clinical findings) or more commonly as (ii) MRI serving an integral role in clinical staging and response evaluation allowing quality-controlled uniform retrospective assessment of MRI accuracy and efficacy. In the first category, and the first prospective study (although observational) was the MERCURY study [33,34] which determined that MRI measurement of tumor penetration into the fat is equivalent to findings at histopathology (to within 0.5mm) and confirmed that a 1mm distance of tumor from the mesorectal fascia (CRM) conferred poorer outcomes. Specifically, MRI was accurate in predicting CRM involvement with an accuracy of 91% and a NPV of 93% in patients that did not receive neoadjuvant therapy. The MERCURY II study [28, 29] revealed a safe low classification system in low rectal tumors. Tailored management based on “safe” low rectal cancer surgical resection plane on baseline MRI enabled optimal clinical management, reducing pathological CRM involvement to 9.0%. In the second category of MRI clinical trial incorporation, Pan-Ex (a pooled analysis of Expert and Expert-C trials testing Cetuximab in KRAS wild type patients) [30] found that mrTRG correlated with the long-term outcome and appeared to stratify patients based on the incremental benefit from sequential CRT. The Quicksilver [23] and RAPIDO trials [40] successfully categorized high- and low-risk patients using MRI-defined criteria to establish that low-risk groups had lower pathologic CRM; lower disease related treatment failures; and lower rates of distant metastases. Although results are not yet published, preliminary data from the TNT [31], OPRA [23] and PROSPECT [20] trials indicate that combining mrTRG with DWI [32], incorporating DWI, T2WI and endoscopy using an expert combined reference standard [33] and arbitrating response to therapy with a 20% reduction in tumor size [Phase II component of PROSPECT passed DSMB safety rules to proceed to Phase III] respectively are probably safe and successful uses of MRI in clinical trials (personal communication Marc Gollub, Radiologic PI or co-PI, all 3 studies). Finally, the phase III TRIGGER trial aims to determine whether patients with locally advanced rectal cancer can be recruited and subsequently randomized into a control trial that offers MRI-directed watch and wait for patients with a good response to CRT (mrTRG1–2) [34].

Fryback and Thornbury [35] created a useful hierarchical model to assess the role and usefulness of new medical technology. If applied to the use of MRI for rectal cancer, of 6 levels ranging from simple Technical Efficacy (Level 1) to Societal Efficacy (Level 6), the above studies firmly place MRI in the “Patient Outcome Efficacy” level (Level 5). As such, MRI is a very well-suited and validated medical test for rectal cancer evaluation [36].

4. European and American Guidelines on Rectal MRI

Rectal cancer management varies across the globe and between professional societies. Table 1 summarizes the main similarities and differences between the most recent guidelines published by the European Society of Gastrointestinal and Abdominal Radiology (ESGAR) [18] and the North American Society of Abdominal Radiology (SAR) [37].

5. MRI Technique

A good quality MRI more often results when a patient already has histopathologic confirmation of rectal cancer, and the tumor position is known from endoscopy. A distance estimation on MRI usually correlates quite well with endoscopy [38, 39] and can help avoid errors in tumor identification. We have also found (MJG, MCF) that high quality images may more often be achieved with the use of spasmolytics to reduce bowel peristalsis and with a 5-mL micro-enema administered just before the acquisition of MRI to reduce gas-related artifacts on DWI [40]. However, there is little consensus on their use. Some experts also recommend endorectal filling to help localize and depict the tumor [41], but this is not recommended by ESGAR or SAR guidelines [18, 37] and was shown not to improve tumor staging. Additionally, it can actually alter the distance of the tumor from the anorectal junction and mesorectal fascia [42].

The workhorse and obligatory MRI sequence is high-resolution fast spin-echo (FSE) T2-weighted (T2W) imaging. This depicts tumor and surrounding fat and organs with the highest intrinsic signal differences (contrast) allowing accurate differentiation. These sequences should be performed in sagittal, coronal, and axial planes perpendicular and parallel to the tumor axis using 3mm-slices and a field of view of 16cm (using 256 matrix) or 20 cm (using 384 matrix) and requires a minimum of 4 signal averages per acquisition. This gives an in-plane resolution of 0.6mm × 0.6mm and a voxel size of 1.1mm3. This allows an accurate assessment of the depth of invasion and involvement of adjacent structures and the correct distance from the mesorectal fascia [18, 37]. In low rectal tumors near or involving the anal sphincter complex, an additional high-resolution T2W oblique coronal parallel to the anal canal should be performed to assess the tumor relationship with the sphincter complex. For all tumors there should be coverage of the mesorectum for a minimum of 5cm above the upper border of the tumor to ensure that upward spread is also imaged at high resolution. In addition, a whole pelvis, larger field of view T2W sequence must be added to assess the nodes from the inferior mesenteric artery origin and caudad (e.g., common iliac nodes at the aortic bifurcation).

Gadolinium based contrast agent (GBCA) during MRI is optional and not recommended by ESGAR or SAR. Its use did not improve the diagnostic accuracy of T-staging, mesorectal fascia involvement, or invasion of adjacent organs in several independent, retrospective staging studies [43–45]. In the research arena, some studies showed that quantitative and qualitative features using GBCA-based DCE-MRI could help in detecting complete tumor response at restaging MRI [46–48].

There is an increasing recognition and validation of the importance of DWI in rectal cancer predominantly at restaging MRI by some researchers [49]. Other researchers would argue that in the absence of long-term outcome data, DWI remains a research tool given that it does not provide superior accuracy in identification of known and validated prognostic factors assessed using high resolution T2W sequences i.e. T depth >5mm, mrEMVI status pre and post treatment, mrTRG, mrCRM and mr Low Rectal stage [50–54]. Although the European consensus guidelines (ESGAR) only recommend DWI at restaging, the American guidelines recommend DWI at baseline also since it may increase the conspicuity of small

primary tumors and nodes [18, 37]. Reduced field-of-view (FOV) DWI may provide better image quality of the primary tumor, and some authors have suggested that it may provide better diagnostic accuracy than full FOV DWI in the evaluation of CR at restaging [55–57].

5.1 Anatomy

Familiarity with rectal and pelvic anatomy is crucial for proper interpretation of rectal MRI. The definition of the rectum can be vague and confusing, and only more recently have there been efforts to attempt to clarify and standardize its definition in order to enhance patient management. One of the authors (MJG) can attest to upcoming proposed changes, based on ongoing discussions in the AJCC 9th edition committee, where instead of the arbitrary tripartite division based on millimetric measurement from the anal verge, a more physiologic and treatment-relevant anatomic division might be used with such landmarks as the anorectal junction [FIGURE 1], the anterior peritoneal reflection [FIGURE 2], and the “sigmoid takeoff” [FIGURE 3].

The sigmoid take-off has been proposed as a useful radiological landmark to define the transition between the rectum and colon [58, 59]. It marks the confluence of the sigmoid mesocolon and mesorectum and is located where the sigmoid colon diverges from the sacrum in a ventral direction in the axial plane and takes a horizontal course in the sagittal plane. Currently, the most common definition is that the rectum is divided into three segments: upper, mid, and lower; arbitrarily set by the distance from the anal verge (0–5 cm, >5–10 cm, and >10–15 cm, respectively) [60]. The mesorectum is a compartment that surrounds the rectum composed mainly of fat, contains lymphatic structures and neurovascular bundles, and is enveloped by the mesorectal fascia. The mesorectal fascia is seen on MRI as a thin hypointense line on T2WI [60] and is caudally contiguous with the intersphincteric space and cranially with the peritoneal reflections [61]. Tumor involvement of the anal canal usually via growth of adenocarcinoma caudally from the dentate line is a common scenario in rectal cancer, and staging is slightly different. A working knowledge of anal canal anatomy is essential, including the internal anal sphincter, external anal sphincter, intersphincteric space and the levator ani muscles [FIGURE 4]. Staging challenges for such tumors will be discussed below.

6. Baseline Staging MRI

6.1 Location, size, and morphology

Tumor location should be described as the distance from the inferior most aspect of the anal canal (“anal verge”) and from the upper most aspect of the anal canal (“anorectal junction”) to the most caudal aspect of the tumor and also may be specified with respect to its circumferential position (e.g., 12 o’clock to 7 o’clock). Although there is no consensus for which and how many dimensions should be reported, most commonly, the craniocaudal dimension and maximal wall thickness are described. Tumor morphology may be characterized as polypoid, circumferential, or partly circumferential or equivalent terms. Although tumor morphology does not determine the T stage, one study has shown that polypoid tumors are often associated with lower pathologic T and N stages [62]. In addition,

the invasive border is the portion of the tumor with the deepest invasion and is usually located in the center of the lesion.

6.2 TNM staging

The American Joint Committee on Cancer/Union for International Cancer Control (AJCC/UICC) tumor-node-metastasis (TNM) system has been an accepted standard around the world for rectal and other cancers. However, in rectal cancer, it has recently been suggested to place too much emphasis on lymph nodes while overlooking other routes available for metastases, such as via veins, lymphatics, and nerves [63]. Overlap between prognostic subgroups based on T and N stages alone exist (i.e., patients with stage IIc disease perform worse than patients with stage IIIa disease) underlining this limitation [64]. New iterations are in the works at AJCC and elsewhere which -it is hoped- may recognize these under-appreciated pathways of tumor spread.

6.2.1 T staging—The depth of the tumor invasion through the rectal wall into the mesorectal fat and/or into adjacent organs defines the T-category. A meta-analysis showed that the pooled sensitivity and specificity of MRI were 87% and 75% respectively, for T staging [65].

The differentiation between T1 (tumor limited to submucosa) and T2 tumors (tumor invading muscularis propria) [FIGURE 5] may be challenging on MRI due to an inherent soft tissue resolution limitation between tumor signal and muscularis propria signal.

For those early-stage cases, ERUS is recommended since it has shown better specificity with similar sensitivity [66]. The muscularis propria is seen as a T2W hypointense layer on MRI, and its infiltration by intermediate signal intensity tumor, when special attention is given to its inner border, may suggest invasion and thereby a T2 tumor, with an accuracy of 67% [50]. A recent study suggests that with the use of GBCA, there is a “submucosal-enhancing-stripe-sign”, which has an accuracy of 87%, in differentiating T0-T1 from T2 tumors[67]. The high signal intensity of the submucosal layer stripe is also readily appreciated on high resolution T2 and has also been shown to distinguish early T1 from T1sm3/early T2; an ongoing trial (PRESERVE trial) is investigating the role of MRI, based on measuring the degree of preservation of the muscularis propria and submucosa in guiding the approach of early rectal tumor and therefore directing favorable patients towards local excision [68].

T3 tumor exists when tumor extends beyond the muscularis propria into the mesorectal fat [FIGURE 6]. Some authors have described inaccuracies differentiating between deep T2 and early T3 lesions. It can be hard to distinguish true mesorectal tumor invasion from desmoplastic reaction [66]. Desmoplastic reaction is typically seen as thin hypointense spiculations, while true tumor extension shows a more nodular/irregular character with an intermediate signal [60]. However, this differentiation may be more relevant when considering the USA guidelines since T2 vs. T3 can be a pivotal cut-off (in the absence of suspicious lymph nodes) as an indication for neoadjuvant treatment. Whereas the European guidelines more commonly use T3 with the extramural extension of <5mm vs. ≥5mm to tailor the treatment [FIGURE 7]. Nevertheless, the MERCURY group found that MRI was feasible and reproducible in measuring the depth of extramural tumor spread and that MRI

and histopathologic assessments were considered equivalent to within 0.5 mm; in this trial radiologists ignored fine spiculations as simply representing expected desmoplastic reaction at the base of ulcerating tumors [50].

T4 is defined as involvement of adjacent organs and “other structures”- T4a when involving only the visceral peritoneum and T4b when involving organs and “adjacent structures”. Anterior peritoneal reflection (APR) involvement may manifest with direct tumor extension, thickening, and irregularity. Upper, anterior rectal tumors have a close relationship to the APR. Criteria to determine involvement at MRI are currently undefined. Even among pathologists, agreement is limited.

Although the AJCC 8th edition manual does not clearly define what ‘adjacent structures’ means in the T4b stage, there is a consensus among the members of the AJCC 9th edition committee (personal communication, Marc Gollub, 12/3/21) that the following structures should be included: pelvic organs (such as the bladder, prostate and uterus), bone (direct invasion not hematogenous spread), pelvic floor muscles (including levator ani, ischiococcygeus, puborectalis and external sphincter), urethra and ureters, sciatic and sacral nerves, vessels outside the mesorectum, small bowel loops in the pelvis, and any fat outside the mesorectum. Therefore it is possible to have tumor involving the mesorectal fascia but still be classified as T3

6.2.2 N staging—Accurate nodal staging remains one of the most challenging components of the preoperative evaluation. Multiple different criteria for lymph node staging have been proposed with varying, but consistently limited sensitivities and specificities. Traditional MRI methods have only moderate accuracy for predicting lymph node metastases if size is used to define involvement since there is considerable size overlap between benign and malignant lymph nodes [69]. High-resolution MRI-defined morphological criteria improve the accuracy of nodal staging. Studies have shown that size alone has low accuracy, but using morphological criteria based on the shape, border, and signal intensity features increases accuracy [69, 70]. It should be noted however, that lymph nodes <3mm are particularly difficult to characterize on current MRI, if at all, and up to 15% of these will be malignant [71]. Benign lymph nodes are homogenous with a regular contour, and malignant lymph nodes demonstrate heterogeneity and irregular borders [69]. A hybrid system combining size and morphology has been instituted for many years in Holland and, termed the “Dutch Consensus Criteria,” resulted in a reduction in over-staging [18].

Nevertheless, studies have demonstrated a reduction in the significance of mesorectal nodal status if a good quality TME with negative CRM is performed, and nodal status predicted local recurrence only when the patient underwent a non-TME or a TME surgery with incomplete specimens [53, 72, 73]. This finding and other similar ones call into question the mechanistic view that tumor spreads to LN and then to distant sites. In fact, a recent study showed that there was a 65% discordance in the sub-clonal origin of LN metastases compared with distant metastases [74]. Some even feel that a LN “traps” tumor and induces an immunological response, possibly even benefitting the patient [75]. While venous exit of tumor cells from a LN may occur, it may be more likely that primary tumor spreads

via veins, nerves or lymphatic channels and are more common routes to distant metastases. So far, compared with lymph nodes, the MRI assessment of EMVI both as contiguous and discontinuous spread indicates that the vascular pathways of spread as depicted by MRI are prognostically more meaningful and more accurate. Brown et al. recommend that since tumor deposits or EMVI are the only features that are prognostically relevant for recurrent disease, radiologists should stage tumor based on the presence or absence of these features rather than attempting the prognostically inadequate MRI staging of lymph nodes [8]. Furthermore, since 40% of rectal cancer patients exhibit this feature, it would be logical to ensure that such patients receive preoperative therapy and also undergo close surveillance. Of necessity, more clinical trials are underway to prospectively gain a better understanding of the pathways of spread on imaging and how they can be disrupted to improve cancer survival [76].

On the other hand, extra-mesorectal lymph nodes (also called lateral lymph nodes, LLN) are not routinely resected and should be carefully assessed since, if suspicious, they may require additional morbid surgery risking bladder and sexual impairment. The nodes most often involved are internal iliac and obturator. These are still considered locoregional, whereas external iliac lymph nodes, inguinal and paraaortic lymph nodes are considered metastatic disease (M1). Recently the Lateral Lymph Node Consortium Study has derived some potentially useful criteria for suspicious nodes on MRI. This large multicenter study showed that nodes with a short axis diameter ≥ 7mm on pretreatment MRI in patients with low LARC (0–8 cm form the anal verge) were associated with an unacceptably high risk of lateral local recurrence (LLR) of 19.5% and thus, this was suggested as a reasonable cutoff size [25]. However, the choice of what an acceptable LLR is purely arbitrary, and the study did find a direct relationship between an increasing size of nodes and an increasing LLR if the nodes were not removed by LLND [25]. Based on the immunological protective theory of nodes, it may be argued that perhaps these nodes are not responsible for cancer death, and therefore a reduction in LLR does not equate to an improvement in survival.

6.2.3 M staging—Similar to colon cancer, rectal cancer most commonly metastasizes to the liver, lung and peritoneum. The vast majority of metastases will be detected using whole-body imaging with CT, MRI or combined PET/CT or PET/MRI. During locoregional staging with pelvic MRI, one may detect nodal metastases considered M1 (inguinal, external iliac and paraaortic lymph nodes). In cases of peritoneal carcinomatosis, implants can be detected in the pelvic cul-de-sac or elsewhere. Bone metastases are distinctly uncommon in rectal cancer, and if present are rarely seen in the absence of non-pelvic, often widespread M1 [77].

7. Beyond TNM

TNM staging, while essential, fails to convey all the necessary information about rectal cancer required by the multidisciplinary team to make management decisions because other evidence-based high and low risk factors have been found to be of utmost importance including; the circumferential resection margin (CRM), involvement of the anal canal, EMVI, tumor deposits (TD) (currently not captured well by AJCC staging), the presence of

significant tumor mucin and the relationship of the tumor to the peritoneal reflection. We elaborate on these risk factors below.

7.1 CRM

The mesorectal fascia (MRF), which encircles the fatty mesorectum surrounding the rectum, forms the plane of dissection in TME surgery and is the intended safe anatomic surgical margin CRM. Achievement of this radial plane is challenging, and gross specimens are carefully observed to ensure that a glistening serosal surface is preserved [FIGURE 8] and that at the level of the pelvic floor, no “waist” is present to suggest incursion into the mesorectal fat [72].

Tumor within 1 mm of the mesorecta fascia strongly predicts poor oncological outcomes and is one of the main determinants of local recurrence [78]. Therefore, it is essential at MRI to preoperatively evaluate the relationship between tumor and the MRF to risk-stratify a patient who may require treatment. Fortunately, MRI has been shown to be highly accurate in predicting CRM involvement [66, 79]. The tumor-MRF distance should be measured as the shortest distance between the advancing edge of the primary tumor and the closest adjacent mesorectal fascia. A distance of ≤ 1mm is considered involved.

Some clarifications should be made regarding the CRM evaluation. Expressing a distance to the MRF can only be done where MRF exists. At a certain point anteriorly and above the anterior peritoneal reflection, such a measurement is no longer possible, because there is no longer any mesorectal fat to provide a margin. Similarly, at about the sacral promontory the posterior peritoneal reflection exists and laterally there is an oblique course of its attachment to the rectum. These landmarks are not well delineated compared with the anterior peritoneal reflection (APR) [18, 80]. For any component of a high tumor that is lateral and/or posterior, it is valid to express this distance, but anteriorly, we opt to say N/A (not applicable) since tumor is already visibly above the level of the APR.

Moreover, although the prognostic importance of the MRF involvement by the primary tumor is well established, the risk of its involvement by metastatic lymph nodes is of questionable significance. Nagtegaal found that metastatic lymph nodes involving the CRM did not increase the risk for local recurrence compared to those with negative margins [81]. In the MERCURY II study EMVI was an independent risk factor for pathologic CRM involvement and may relate to the fact that unlike lymph nodes which are bounded within the mesorectal compartment, vascular pathways of spread and discontinuous vascular tumor deposits do not respect the mesorectal fascia as a boundary [28].

7.2 Anal sphincter status

One of the surgeon’s primary goals (and challenges) for low rectal tumors is to preserve sphincter function without compromising oncological outcomes. Abdominopelvic resection is the conventional operation for low rectal tumors involving more than just a small upper portion of the anal sphincter, but it is associated with high local recurrence rates and morbidity [82]. Neoadjuvant chemoradiation has been shown to be helpful in downstaging tumors that initially involve the sphincter complex and at times may allow for sphincter preservation surgery; however, radiation to the anal sphincter itself compromises sphincter

functionality and increases anastomotic leak rates [83]. Moreover, additional dissection planes have emerged depending on which component of the anal sphincter is involved and at times a wider excision will also remove the levator ani muscles (extra-levator abdominoperineal excision (AKA ELAPE)) [83].

MRI is particularly well suited as a non-invasive way to determine the safety of the distal TME plane – where the mesorectum naturally tapers and where the MRF is no longer present. In staging of low rectal cancers, the standard T1-T4 system used above the anorectal ring is not adequate and instead, an assessment based on the radial extent of tumor and the safety of the intersphincteric plane is used to guide the surgical plan. The "Level 1–4" staging system investigated in the MERCURY II study as well as another depth of anal canal invasion study [84] correlates invasion and >1mm clearance of tumor to the intersphincteric plane with surgical outcomes [28, 54, 84] (TABLE 2). As of now, there is no consensus on which system to implement. At our institution, and among USA surgeons, there is a general agreement to use a *prose description* of the relationship of tumor to the internal sphincter, the intersphincteric space, and the external sphincter so as to convey a clear message at a time when no specific staging system is universally accepted.

7.3 EMVI, TD, and PNI

There is an increasing awareness that not every nodule within the mesorectum corresponds to a lymph node, and other entities of extra-nodal mesorectal spread may be at play – TD, EMVI, and perineural invasion (PNI). Studies have shown poorer prognosis associated with those entities [8, 63] with even greater prognostic significance than T and N stage [85].

Histopathologic EMVI is already well recognized as an independent predictor of local and distant recurrence and poor overall survival [86, 87]. More recently, studies have also shown that EMVI detected by MRI, in the pre [7] or post neoadjuvant CRT [52] settings, is also a poor prognostic factor with increased rate of synchronous metastases and of developing metastases after surgery [7]. MRI is now considered a gold standard in the detection of EMVI and can be used to help histopathological awareness [51, 88]. A study performed by Smith et al [51] proposed an MRI-EMVI score (raging 0 to 4) grading the suspicion of EMVI based on MRI. They showed that high scores (3 and 4) were associated with worse relapse-free survival. On MRI, EMVI manifests as tubular or serpiginous structures corresponding to the vessels with signal similar to the tumor (intermediate signal on T2) [FIGURE 9]. In addition, the vessels may show irregular or nodular borders. Although EMVI may or may not occur continuously with the primary tumor, whenever a tumor is near a vessel, EMVI should be considered – and confirmed as such if tumor is expanding and disrupting a vessel on two orthogonal views[89].

Tumor deposits (TD) are nodules of tumor cells within the mesorectum discontinuous from the primary tumor [FIGURE 10], still of uncertain origin, and may occur in association with EMVI [8]. TD was first introduced within the AJCC staging system in the 5th edition in 1977 and, since the 7th edition, has been recognized as the separate category N1c [8]. On MRI, they are seen as nodules with irregular margins, often located along the vessels, but, differently from the lymph nodes, they interrupt the vessel course [85]. Controversy arises however in that the current TNM places pN1c as a lower category than pN2 for

example, and yet outcomes for pN1c are worse [63]. It is thus felt that the current manner of incorporating TD into the TNM system does not properly convey the patient's risk stratum. The current AJCC 9th edition committee is discussing these 2 emerging risk factors and how best to incorporate them into a modern staging system that properly reflects patient risk (personal communication Marc Gollub 12/7/21).

PNI occurs when tumor cells travel along nerve sheaths and is a known poor prognosticator [90]. Its role in causing distant metastases is not yet clear, but it would seem likely to be a risk for local invasion and local recurrence. Here too, more studies are needed.

7.4 Peritoneal reflection

The APR is a landmark that divides the intra- and extra-peritoneal portions of the rectum (anteriorly) and can often be identified on MRI. This landmark has oncological implications since (a) tumors below APR have lymphatic drainage to the pelvic basin whereas tumors above the APR mainly drain to the sigmoid mesentery, (b) below the APR tumors have a worse prognosis with higher risk of local recurrence, (c) APR involvement by the tumor also increases the recurrence risk [91] and is staged as T4a, and finally; (d) the APR approximates the 10-cm distance from the anal verge at which, historically it was determined (in the Dutch TME trial) that there was no survival advantage of administering radiation [92]. Hence, the tumor relationship to the APR could potentially be used to tailor optimal treatment strategies.

On T2W images, APR can be recognized as a hypointense thin line well identified on axial and sagittal planes with its attachment on the anterior rectum with V-shaped configuration on axial plan. The junction of the seminal vesicles in men and the uterocervical angle in women are useful anatomical references to find the APR [93].

7.5 Mucin

Mucin may occur in two different scenarios in rectal tumors: *primary* mucinous tumors and mucinous response to chemoradiation of an originally non-mucinous tumor (sometimes referred to as "colloid degeneration"). Primary mucinous adenocarcinomas are poorly differentiated tumors with poor prognosis and poor response to neoadjuvant chemotherapy [9, 94]. On the other hand, mucinous response is usually a sign of successful treatment and does not carry the poor prognosis primary mucinous tumors do, however its prognostic significance compared to other types of responses is still debatable [95].

MRI has shown good accuracy in differentiating mucinous and non-mucinous tumors [96] and has demonstrated even higher accuracy than presurgical biopsy in detecting mucin due to the randomness of biopsy [97]. Moreover, mucinous tumor defined by baseline MRI have been shown to be an independent imaging biomarker for poor prognosis and poor response to preoperative chemoradiotherapy [97]. On MRI, mucin is identified as very high signal on T2W images [FIGURE 11] and predominantly hypo-enhancing in contrast images. DWI is of limited value due the T2 shine-through effect [98]. Mucinous response may be suggested when there is an increase in tumor signal intensity on T2W relative to pretreatment MRI [99].

Evaluation of response after neoadjuvant therapy in mucinous tumors is challenging since MRI is limited in differentiating cellular from acellular mucin pools and its interpretation remains uncertain. Residual tumor cells within the mucin pools may be suggested by heterogeneity with intermediate signal foci and restricted diffusion [100].

8. Restaging MRI

Assessment of response to neoadjuvant therapy was historically accomplished with endoscopy, clinical assessment, and routine imaging with CT scan to exclude progression or development of metastases. Although baseline tumor evaluation using MRI rapidly established itself as a useful tool and was widely proliferated, the use of MRI for re-staging has been adopted more sluggishly, in part because of confusing appearances of tumor versus the effects of treatment such as fibrosis, inflammation and edema. A meta-analysis of restaging MRI determined just how limited this application of MRI was using conventional T2W sequences [101]. Nonetheless, the rapid proliferation of magnets, radiologist's comfort with MRI and its availability were such that research determined that there were advantages to its use in spite of its limitations. In 2022, it is the preferred method for restaging and is routinely performed in conjunction with clinical and endoscopic evaluation. The modern goals of rectal cancer restaging are: a) to differentiate "good responders" versus "poor responders" in order to personalize therapy b) to differentiate complete response (CR) (yT0N0) from residual tumor (yT1–4), and therein contemplate possible non-operative management ("watch and wait" policy), c) to identify tumors limited to rectal wall (yT0–2N0 versus T3–4 or N+), which might lend themselves to limited surgeries such as transanal excision, and d) to reassess CRM, anal sphincter, and adjacent organ involvement to ensure a safe surgical plane.

8.1 Morphologic and size changes

Scar/fibrosis formation is one of the main responses seen after neoadjuvant therapy. On MRI, it is characterized as very low T2 signal [FIGURE 12], whereas residual tumor manifests as intermediate signal areas. Moreover, fibrosis usually has a low cellular density, resulting in low signal intensity on high b-value DWI [FIGURE 12], while residual tumor has a high cellularity and therefore a high signal intensity on DWI. The extent of fibrosis should be recorded separately from the extent of tumor signal [102]. Nevertheless, MRI is limited in detecting microscopic tumoral cells within the fibrosis. In addition, after radiation, normal rectal wall adjacent to the tumor may show edema and become prominent, which may simulate a tumor and cause confusion in less experienced readers.

Responding tumors also decrease in size after neoadjuvant therapy. Reduction of the tumor volume in > 60–80% correlates with good response [103] and tumor volume reduction rate has been shown to be an independent prognostic factor [104]. However, volumetry is time-consuming and therefore many societies recommend the measurement of the tumor length as a proxy [18, 37].

In a small percentage of cases, the tumor completely disappears with normalization of the rectal wall. In a study, the normalization of rectal wall corresponded to complete response in all cases [105].

8.2 MRI tumor regression grade (mrTRG)

mrTRG is an imaging adaptation from the TRG grading system used in histopathology. It is a 1–5 scale to grade the degree of tumor response after neoadjuvant therapy based on the proportions of fibrosis and residual tumor seen on T2W. It is well established that the pathologic TRG (pTRG) is a significant prognostic factor and predicts overall survival [73]. The MERCURY study showed that the mrTRG also correlated with survival outcomes (disease-free survival and overall survival), and with a greater statistical significance than ymrT [53]. However, other studies showed low agreement between pTRG and mrTRG [106, 107]. Brown et al. hypothesize that mrTRG1–2 represents non-viable tumor within fibrotic stroma and therefore would not correlate with pathology but would correlate with long term lack of tumor regrowth in a watch and wait setting. This hypothesis is being tested in the TRIGGER trial [34].

8.3 ymrTNM (including lateral LN)

8.3.1 ymrT staging—Posttreatment T staging criteria on MRI (ymrTNM) are identical to the baseline staging parameters (mrTNM). However, accuracy of MRI in the posttreatment setting is lower than in pretreatment setting [101]. A meta-analysis has shown an overall low sensitivity of 50.4% with a good sensitivity of 91.2% [101]. DWI increased the sensitivity to 83.6% without significant decrease in specificity (84.8%) [101]. DWI has continued to emerge as a powerful tool in rectal cancer re-evaluation [49].

8.3.2 ymrN staging—As organ preservation therapy has been increasingly considered for good responders to CRT, accurate nodal restaging has become more important. Chemoradiation often decreases the size and quantity of both benign and malignant lymph nodes. MRI restaging using size criteria has been shown to be more accurate for lymph node staging when compared to the baseline scan probably due to the decrease in the number and size of *all* lymph nodes whereby residual enlarged nodes are statistically more likely to be metastatic lymph nodes [108].

In the posttreatment setting, chemoradiation induced fibrosis and inflammatory changes may be responsible for irregular contour and signal intensity heterogeneity in the lymph nodes, and also the lymph nodes get smaller making morphologic features more difficult to evaluate [109]. Therefore, size becomes an important feature. Optimal size cut-offs for short axis have found to be 2.5 mm [108] - 3.3 mm [109] with sensitivity and specificity 85% and 78% and 75% and 64%, respectively. However, the use of a 5mm cut-off has become common and pragmatic with a chance varying only between 11–14% that such a node will contain tumor. Furthermore, one study showed that the absence of nodes at DWI, although not a common finding, was a reliable predictor of yN0 [110].

On the other hand, criteria for tumor risk in lateral lymph nodes (“extra-mesorectal” lymph nodes) have been the topic of a recent, large, multicenter cohort study performed by the Lateral Lymph Node Consortium. This showed a progressive increased risk of local recurrence (LR) with size of the internal iliac and obturator nodes. While no absolute size cutoff existed to confer *no risk*, the Consortium suggested an acceptable risk of LR using a short-axis lateral node size < 7mm on pretreatment MRI. Furthermore, if that criterion

is used, the group noted that shrinkage to ≤ 4mm on post CRT MRI resulted in no local recurrences at 3 years of follow up, suggesting this as a possible cutoff in the decisions about the need to perform lateral lymph node dissection. While the baseline criteria are slowly being adopted in the USA, the post-treatment criteria are felt to be less reliable based on the high variability in treatment types in the study population [24].

8.4 Posttreatment CRM (ymrCRM)

Evaluation of CRM involvement after chemoradiation is more challenging due to the limitation of MRI in identifying residual tumor within fibrosis, and consequently leading to overestimation of local tumor invasion. A study showed that the positive predictive value for pCRM decreased from 80% in the pretreatment setting to 42% in the posttreatment setting [111]. A meta-analysis showed moderate results for CRM restaging with sensitivity of 76% and specificity of 85.9% [101].

8.5 Posttreatment EMVI/TD

EMVI and TD have increasingly been studied on pretreatment MRI; however, only a few studies have investigated their characteristics on MRI after neoadjuvant chemoradiation. Some studies have shown that mrEMVI regression or the replacement of tumor signal within vessels by fibrosis after CRT was associated with improvements in survival outcomes [FIGURE13] [112–114]. Therefore, patients with minimal or no regression of mrEMVI might be considered for intensification of treatment and/or closer follow-up. Validation of existing studies is needed to further understand the implications of this important tumor biomarker, and the ongoing MARVEL study [76] (NCT01995942) is a European multicenter observational study undertaken to accomplish this task.

8.6 Complete response and watch-and-wait policy

Approximately 15–20% of patients with rectal cancer that receive neoadjuvant chemoradiation achieve complete response [115]. In 2004, Habr-Gama et al [116] suggested that surgery could be deferred in a selective group of patients who had clinical complete response after neoadjuvant therapy and that those patients could be closely followed clinically (a strategy known as “wait-and-see” policy). Since then, there has been a rapidly growing interest in organ preservation strategies including local excision and non-operative management. More recent studies have shown promising long-term oncological and functional outcomes [115, 117]. A remaining challenge is how to preoperatively diagnose complete response and safely select patients for organ preservation strategies. The outcomes of the first prospective study, the OPRA trial [23], including an expert-panel created a priori MRI system are eagerly awaited and have been presented at ASCO 2021 [118].

Studies have shown that clinical assessment (DRE and endoscopy) are inadequate to predict complete response. For instance, the presence of ulcer on endoscopy, although significantly associated with pathological incomplete response, occurred in 66% of cases with complete response on pathology. On the other hand, even though absence of mucosal abnormalities or presence of mucosal scarring alone on endoscopy were significantly associated with pathological complete response, 27% of those cases had residual tumor on

surgical pathology [119]. Moreover, endoscopy provides a good assessment of the mucosa, however, it is limited in evaluating possible residual tumor deeper in the rectal wall and mesorectum [120, 121].

The combination of DRE, endoscopy, and MRI (T2W with DWI) seems to give the highest accuracy to predict CR. A seminal study showed that when all three assessments indicate a CR, it was correct in 98% of the cases [122]. Complete response on MRI is suggested when there is a normalization of the rectal wall or when there is only the T2 hypointense scar with no restricted diffusion. DWI has improved the performance of MRI in predicting complete response [123, 124] and in detecting tumor regrowth when an organ preservation strategy was chosen. A recent small study found that while most DWI positive cases corresponded to endoscopy positive cases, false positive DWI was also common. However, in approximately one fifth of cases where there was a positive DWI with a negative endoscopy, endoscopy turned positive later, while DWI remained positive, or increased in the identical location, suggesting that DWI may detect tumor regrowth before endoscopy [121]. However, this remains to be validated. DWI, admittedly, is a fastidious sequence to perform and interpret with myriad artifacts and interpretation nuances including T2 shine through and T2-dark-through, among others [125].

On the flip side, radiologists and surgeons are still missing some cases of CR. Some studies have found that when MRI or endoscopy indicated residual tumors approximately 15% of the cases were in fact CR on surgical pathology [122, 126]. The most common pitfalls on those false positive cases were mucosal abnormalities on endoscopy, mixed signal, or irregular appearance on T2W, residual high signal on DWI, and over-staging nodes [127].

As discussed previously, one of the main limitations of MRI is the nodal assessment. It is accepted that the response on lymph nodes tends to follow the response on the primary tumor. However, the risk of residual nodal disease when a complete response is reached in the primary tumor is variable in the literature, from as low as 1.8–5% [115, 128] to as high as 17% [129].

9. Beyond TME-Surgery and the Role of MRI

Recurrent rectal tumors and locally advanced primary rectal cancers that have spread beyond the TME planes are challenging due to necessity of more complex surgeries to achieve complete resection with negative surgical margins (R0). Those surgeries are composed of pelvic exenterations or multivisceral/multicompartmental resections of adjacent organs or of the pelvic sidewall and they may require surgeons from different specialties with high expertise. An R0 surgery improves the oncological outcomes, but at the expense of increased morbidity and postoperative mortality [130, 131]. Therefore, patient selection should be done carefully.

MRI has been shown to have a high accuracy to determine invasion of adjacent organs and may be used to select eligible patients for surgery and as a road map for surgical planning [132, 133]. A classification into seven anatomical compartments according to the fascial limits and the anatomical planes of dissection has been suggested [134]. The same

study investigated the performance of MRI detecting invasion of each pelvic compartment [134] and showed that MRI has a sensitivity superior to 93.3% in all except for the lateral compartment where it was 89.3%. Another simplified classification recently proposed has shown that a peri-anastomotic recurrence is associate with better DFS after salvage surgery [135]. The Beyond TME trial [136] is an ongoing multicenter prospective trial that has been studying the role of MRI in selecting and guiding surgery.

10. Non-Standard MRI Biomarkers

Quantitation of diffusion weighted imaging using pharmacokinetic modeling results in the apparent diffusion coefficient (ADC). The ADC-value has also been investigated as a biomarker in LARC. Studies have shown that ADC-value of the primary tumor can help predict tumor aggressiveness [137], presence of nodal metastases [138–140] and of distant metastases [139]. Moreover, it can also be helpful in predicting CR on restaging MRI, with an accuracy of 87% but a low PPV of 52%, probably due to significant overlap of ADC values between CR and near-CR [141]. These promising small retrospective studies also await large-scale prospective validation.

DCE-MRI is a technique that can assess the tumor vascularity and therefore provide information regarding aggressiveness and degree of angiogenesis and by extension hypoxia, all important features of the microenvironment. The value of quantitative and semiquantitative features extracted from DCE-MRI in rectal cancer has been investigated. A systematic review showed that high K^{trans} before CRT and a reduction of K^{trans} of 32% −36% was associated with good response [48]. The future role of DCE-MRI is unclear given the agreement among guidelines that GBCA are not required for the evaluation of rectal cancer during MRI. As such, similar to quantitative DWI (ADC and IVIM) these techniques remain largely in the research arena.

11. Structured Reports

The introduction of proformas, or structured (sometimes synoptic) reporting improves the completeness of rectal cancer assessment reports significantly [142, 143]. A prospective study showed that crucial information for therapeutic decisions on oncologic staging imaging were missing in 52% of radiology reports with an improvement of 78% in report completeness after the implementation of structured reports [144].

12. New Frontiers: MR-Based Radiomics

Radiomics and radiogenomics have been targets of investigation in the last several years for several types of cancers, including rectal cancer. Radiomics refers to the extraction of a vast number of qualitative and quantitative features from routine images using a computer that are effectively invisible to the human eye [145]. Several studies have been investigating the association between radiomics and different endpoints, including prognosis and survival [146], prediction of pathological complete response on baseline MRI [147] and on restaging MRI [148], genetic profiles of tumors (radiogenomics) [149], and prediction of distant metastases [150]. Although promising, the generalizability and therefore applicability into

clinical practice is still limited and further prospective, multicenter, and standardized studies are needed.

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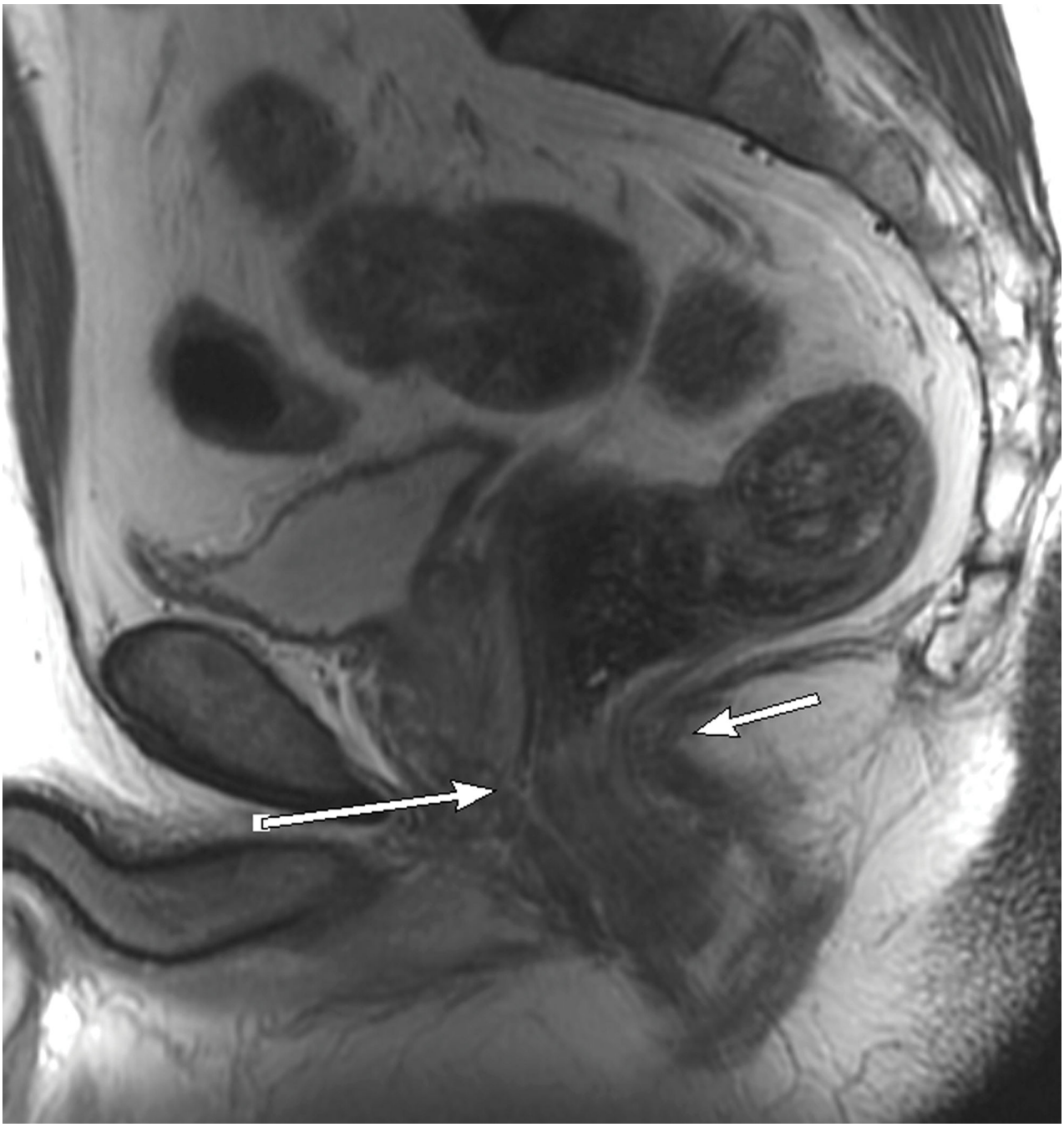


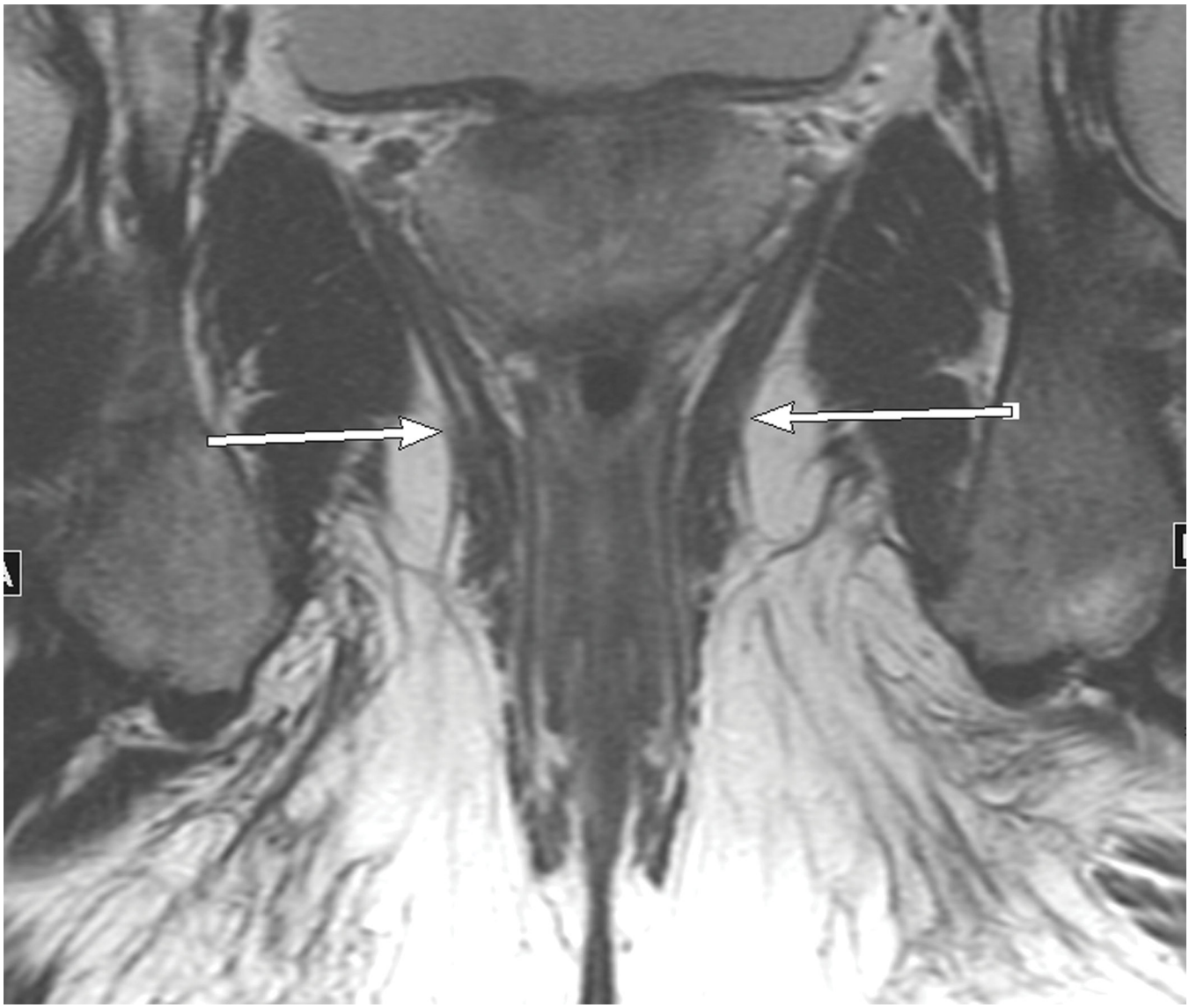


Figure 1.
Sagittal and coronal T2W MR pelvis images through the pelvic floor in a 52-year-old male with rectal cancer. Arrows indicate top of puborectalis/pubococcygeus muscles denoting the anorectal junction or “ring”.

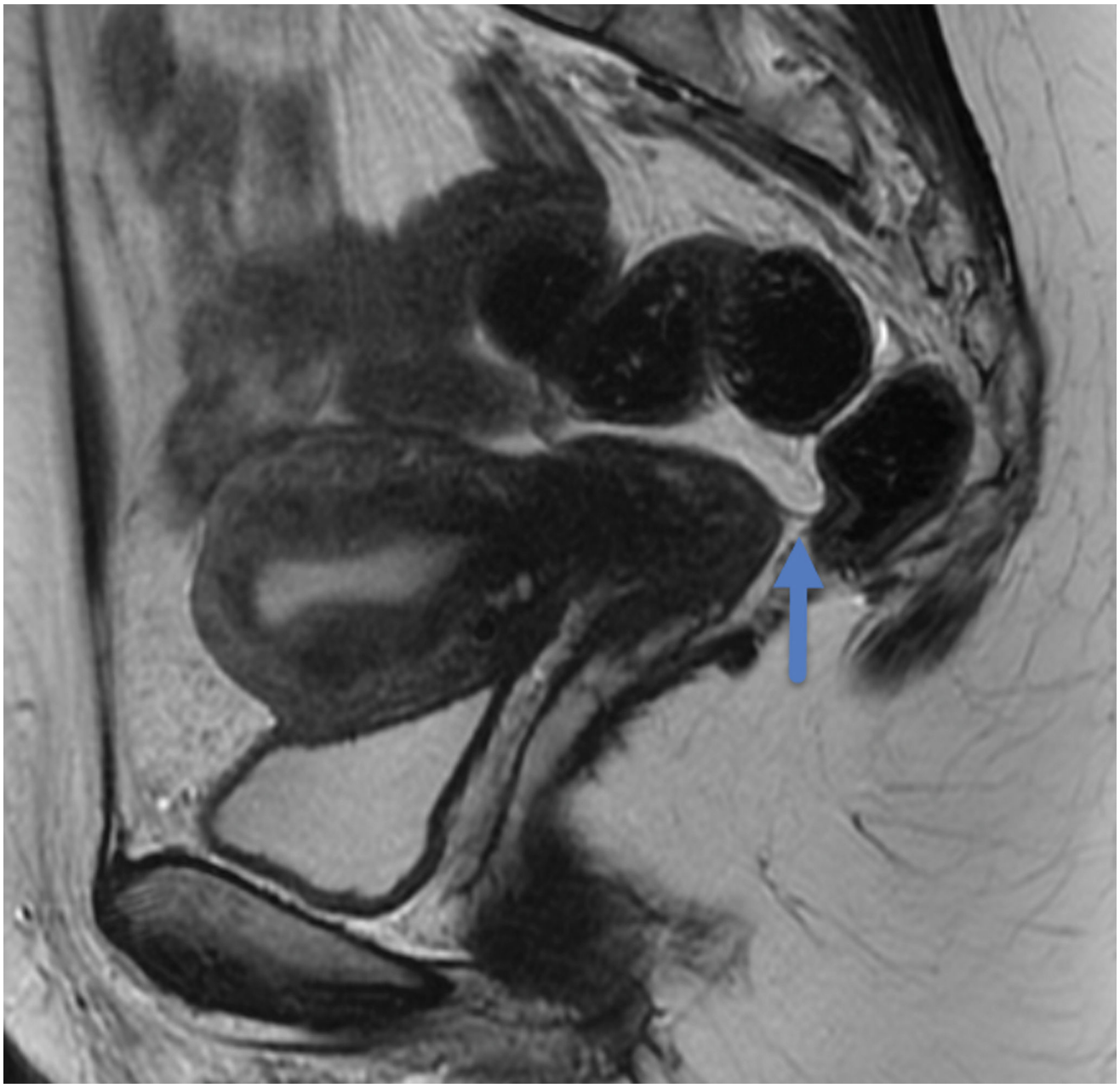


Figure 2.
Sagittal T2W MR of the pelvis in a 33-year-old female with rectal cancer. Arrow indicates the thin black line, the Anterior peritoneal reflection, inserting onto the rectum at the cul-de-sac.

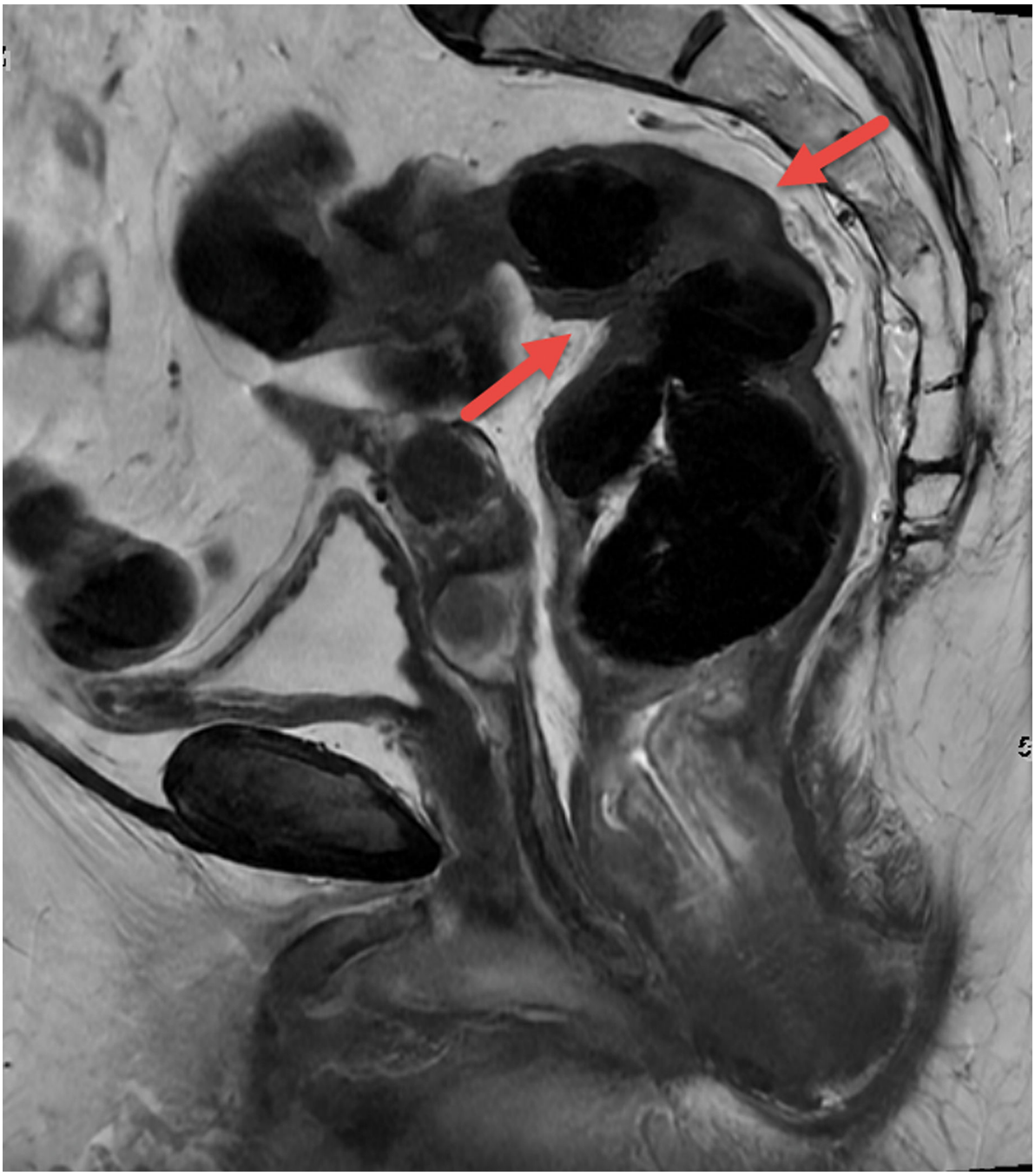
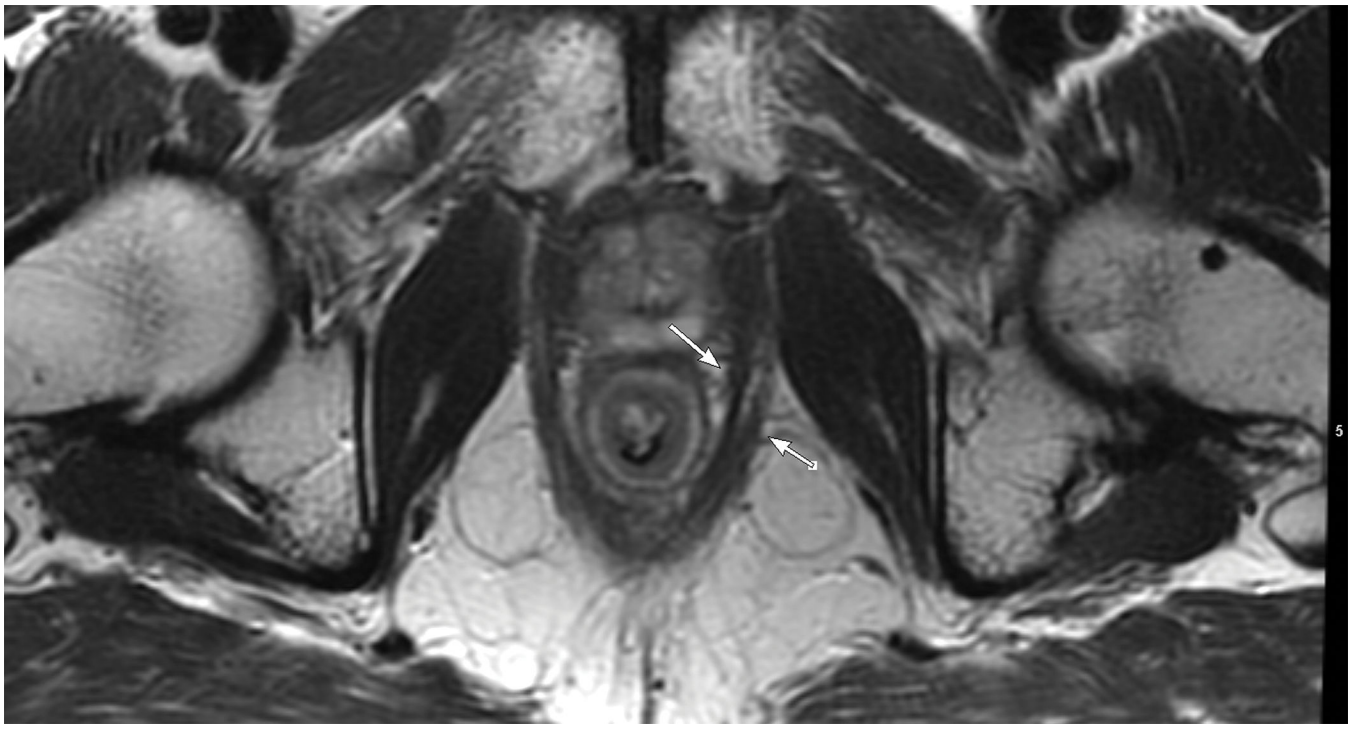
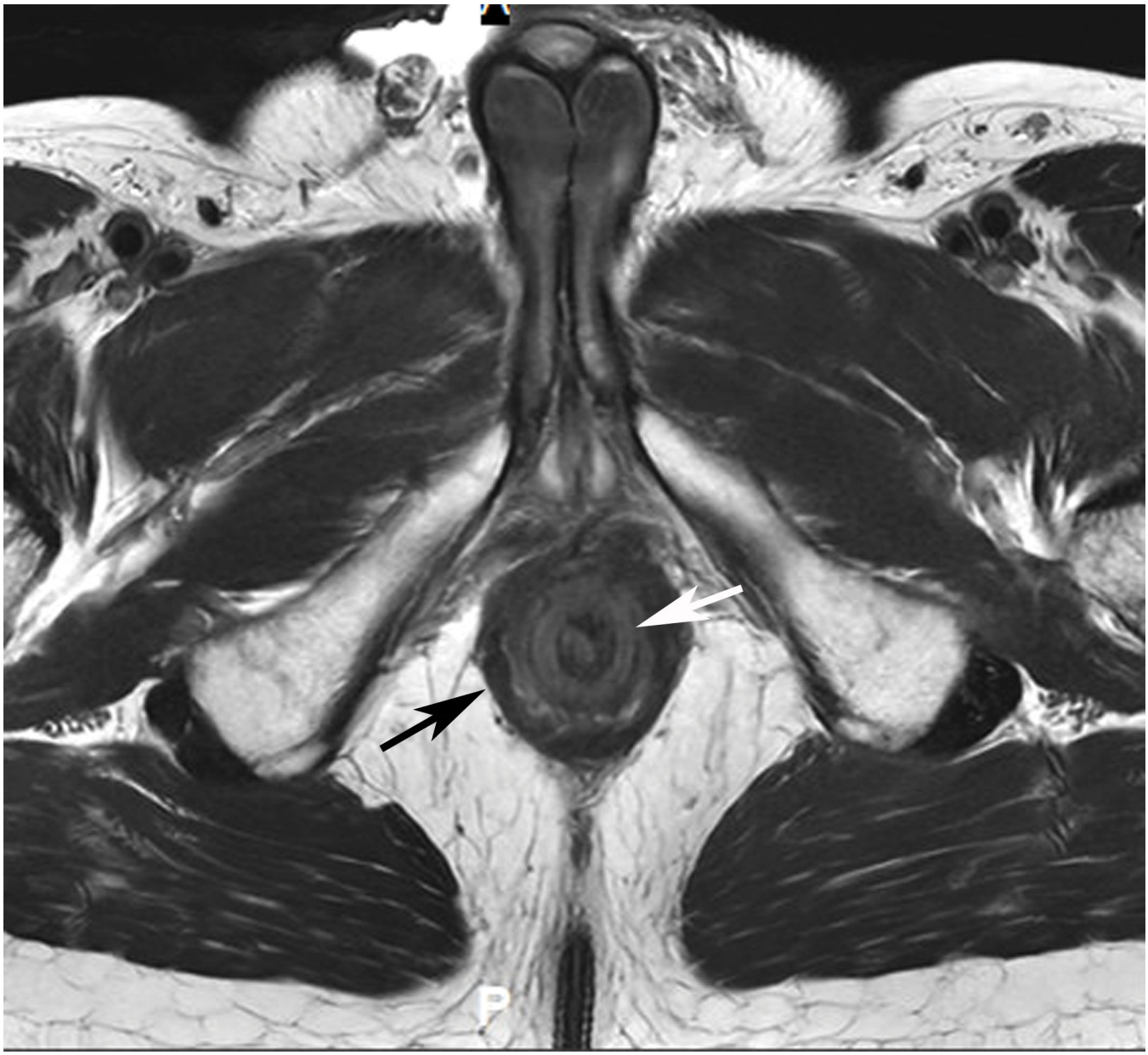


Figure 3.
Sagittal T2W MRI of pelvis in a 73-year-old old female with rectal cancer. Arrows indicate the acute forward angulation of the rectum (sigmoid takeoff) to become the horizontally oriented sigmoid colon.





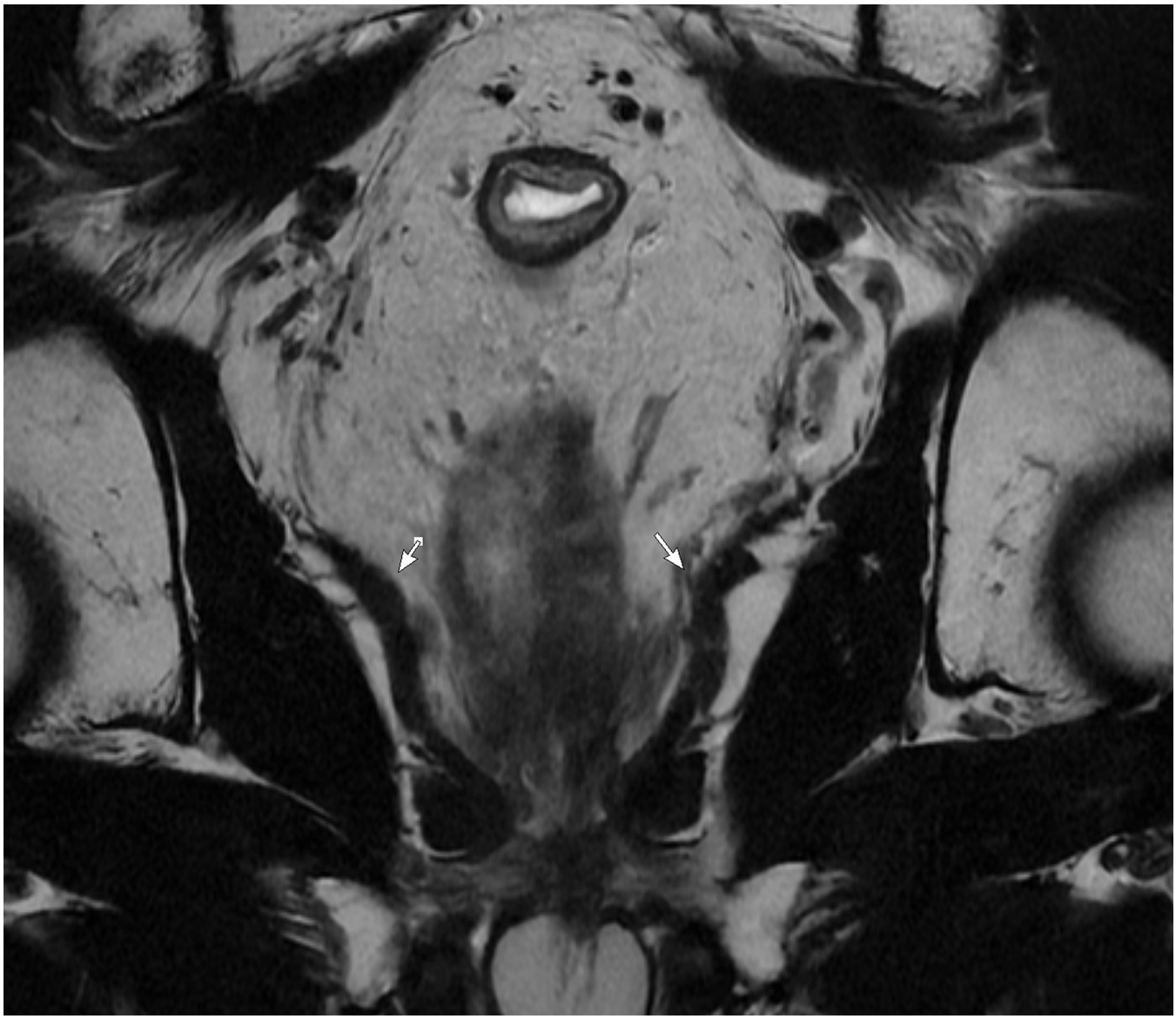


Figure 4.

Axial (A) and (B) and Coronal (B) T2W pelvic MRI in 59-year-old male with rectal cancer after treatment. The levator ani muscles comprise the puborectalis (inner thin arrow in (A), the pubococcygeus muscle (outer thin arrow in (A), and the iliococcygeus muscle (small arrows in (C). The anal sphincter muscles include external (black arrow (B)) and the internal (white arrow in (B)). Note the scar in the tumor bed at 6 pm in (A).

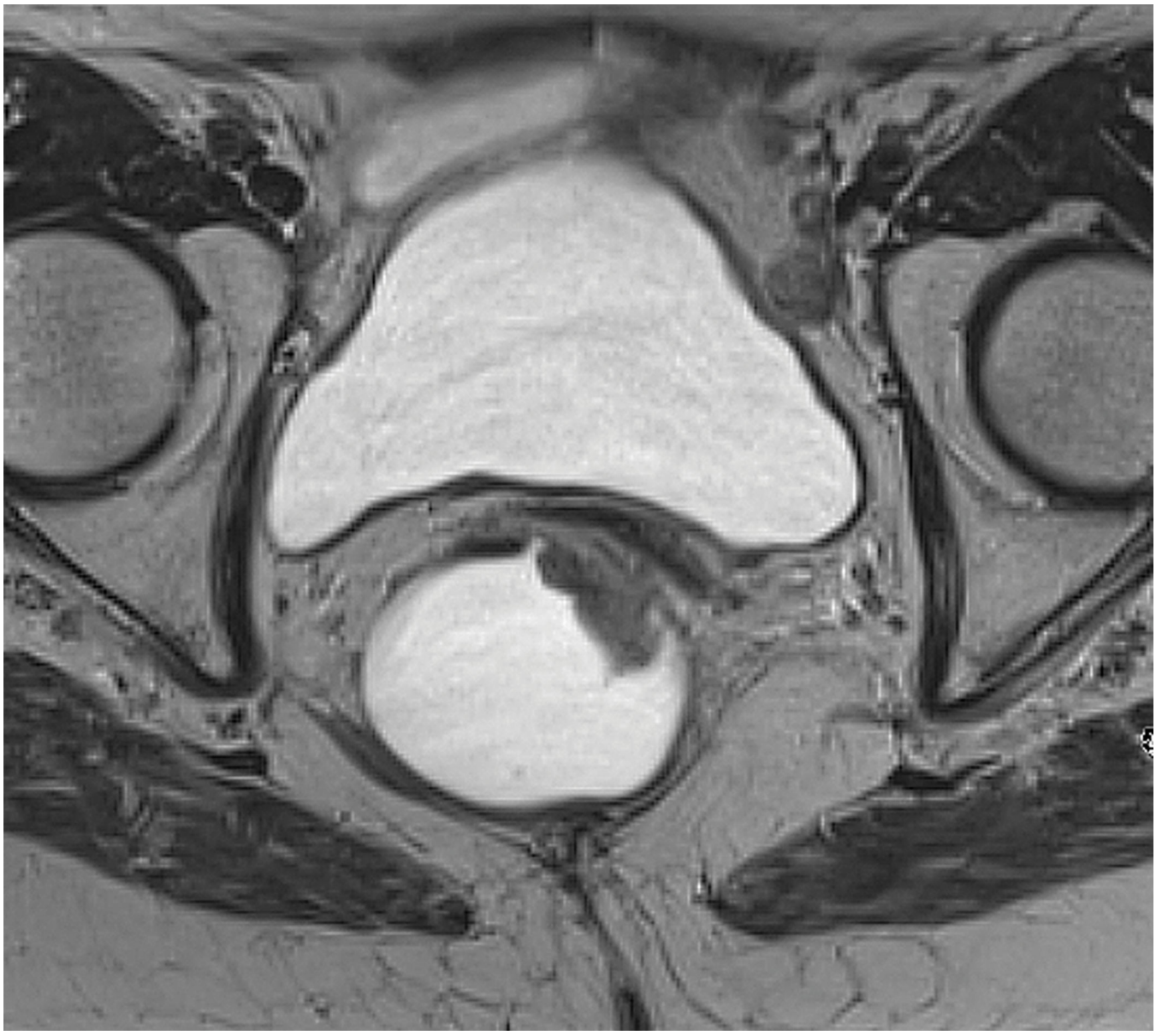


Figure 5.

Axial T2W pelvic MRI in a 79-year-old female who underwent rectal filling. A sessile tumor between 12–2 PM is either T1 or T2 – but careful scrutiny of the muscularis propria shows its full preservation at the epicenter of the lesion indicating greater certainty of mrT1 stage and potentially amenable to local excision by TEM or TAMIS.

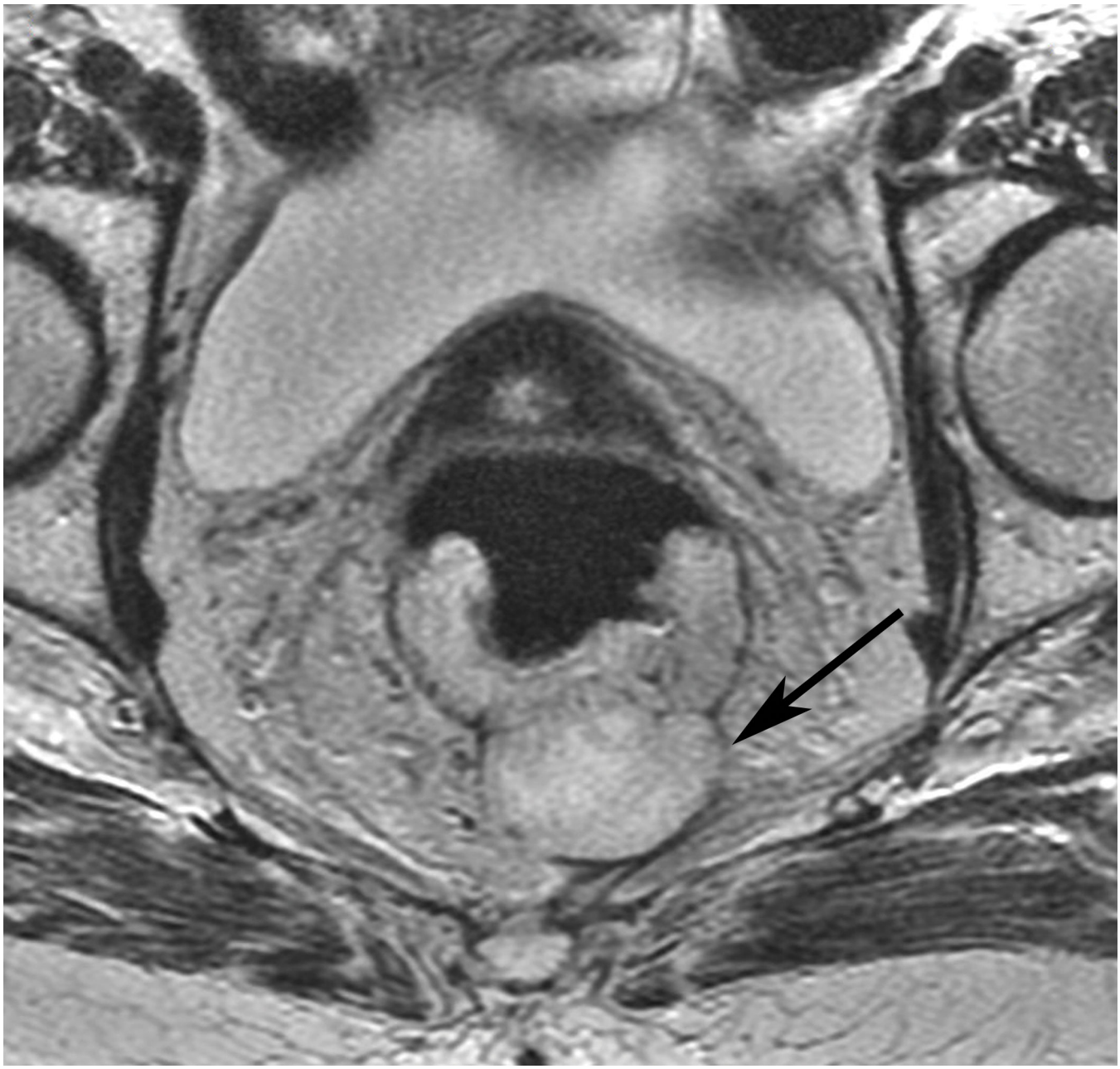
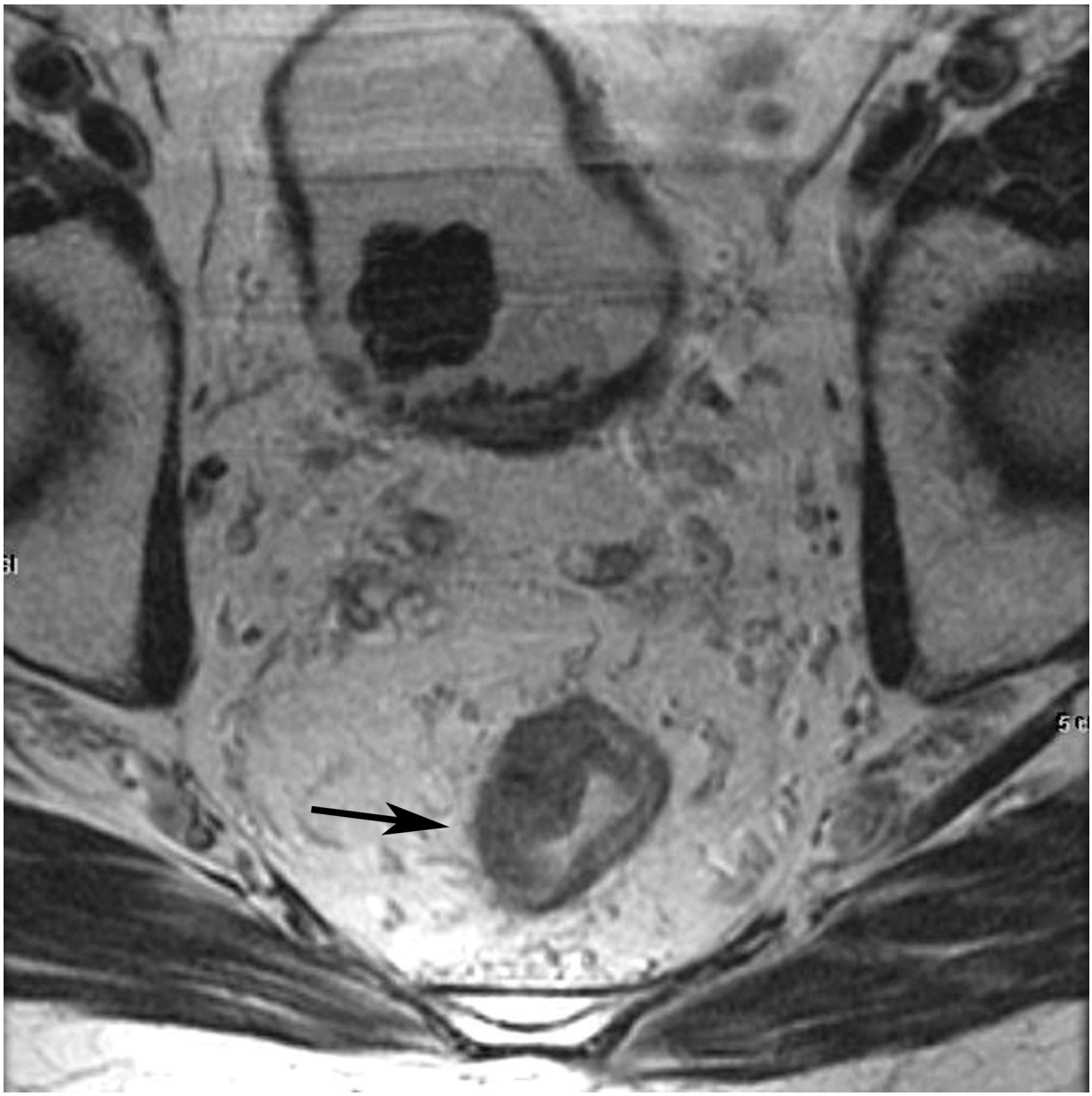


Figure 6.
Axial T2W pelvic MR in an 87-year-old female with T3 rectal cancer deeply penetrating wall at 5 pm position and mostly consisting of mucin.



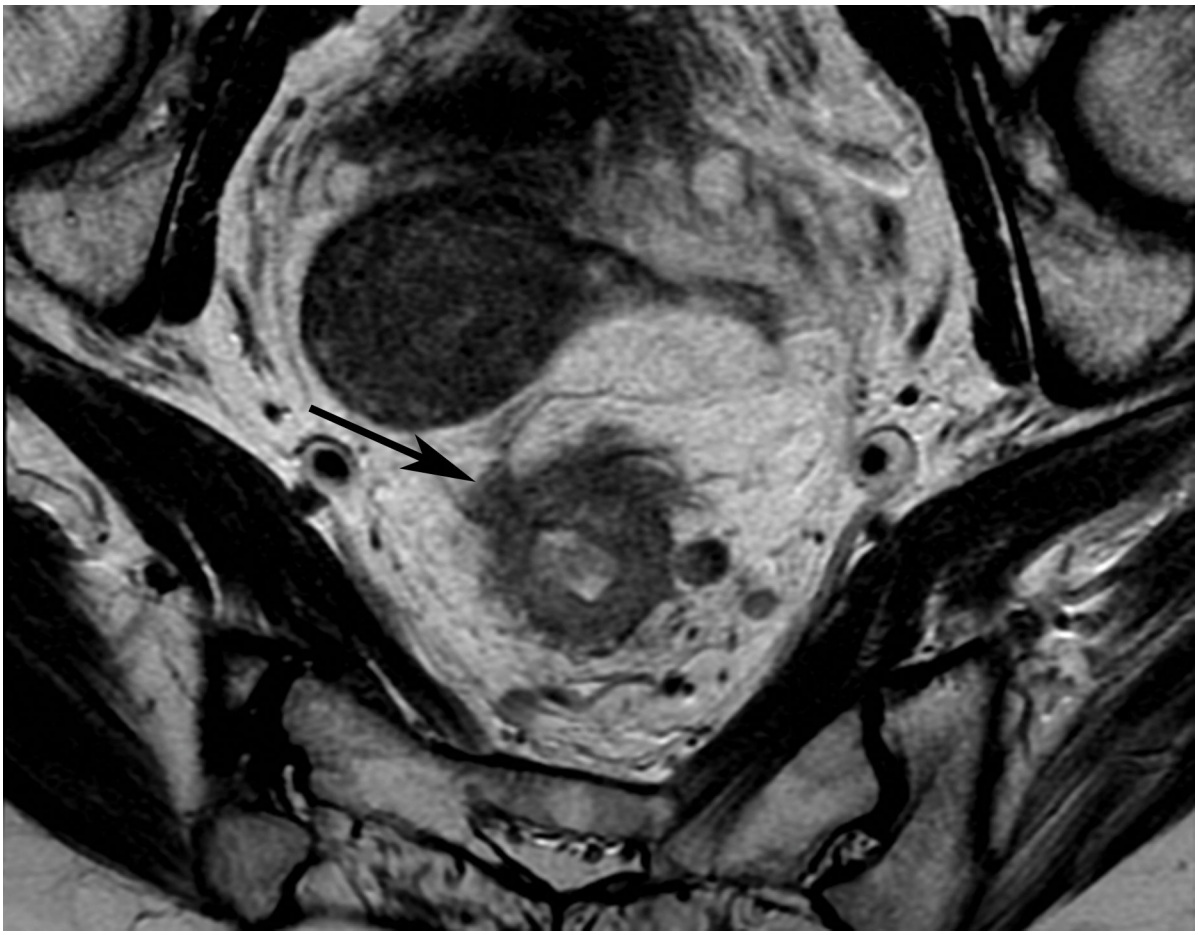


Figure 7.
Axial T2W pelvic MR in middle aged male patient with T3 rectal cancer. On the left with < than 5mm of penetration from 6–9 pm and on the right, in a 48-year-old female with > 5mm at 10pm.

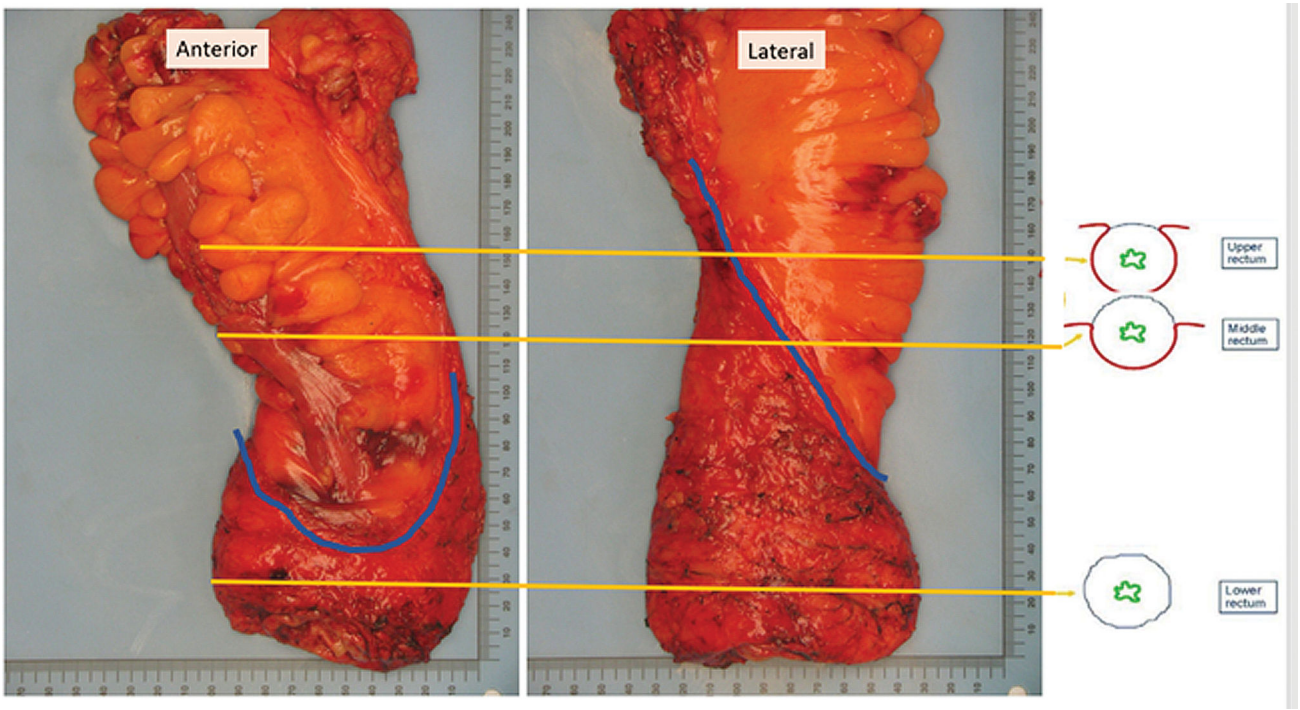


Figure 8.

Gross pathologic specimen from TME surgery; anterior and lateral. The blue line demarcates the peritoneal attachment which runs obliquely cephalad on the lateral Rectum. The lower, redder rectum is surrounded by the thin shiny intact mesorectal fascia. Superiorly, the fat of the sigmoid mesocolon is noted. Courtesy of Dr Jinru Shia Attending Pathologist Memorial Sloan Kettering Cancer Center.

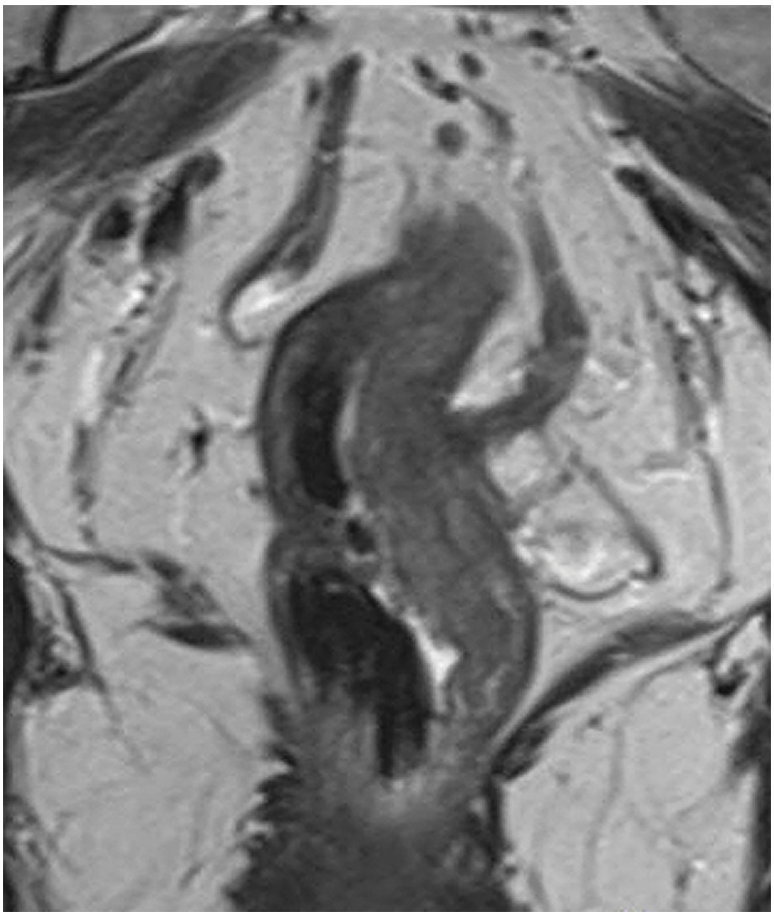


Figure 9.
Coronal T2W pelvic MR in 37-year-old female with rectal cancer and left-sided EMVI

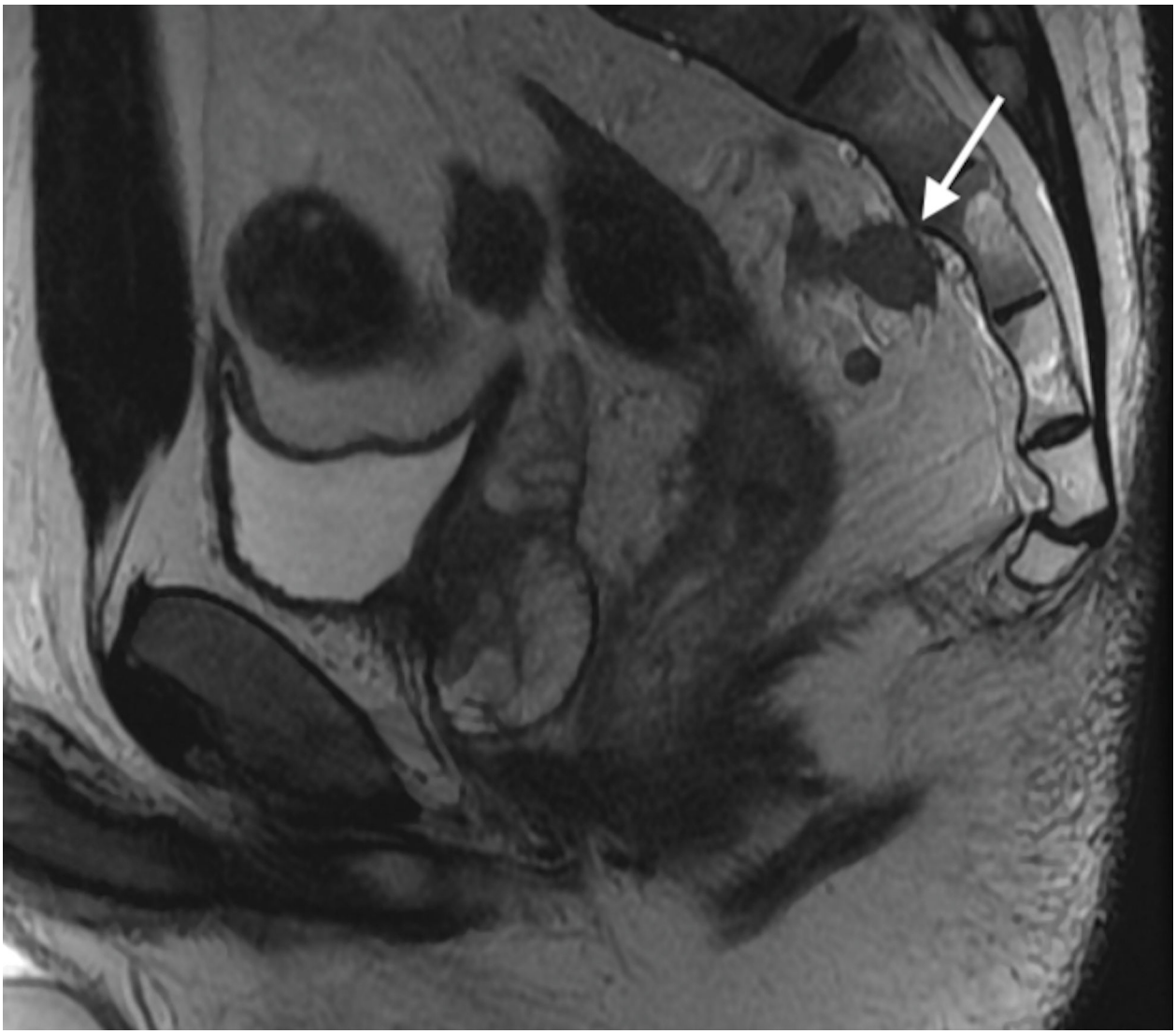


Figure 10.
Sagittal T2W shows a posterior mesorectal irregular nodule arising from and interrupting the superior rectal vessel consistent with tumor deposit.

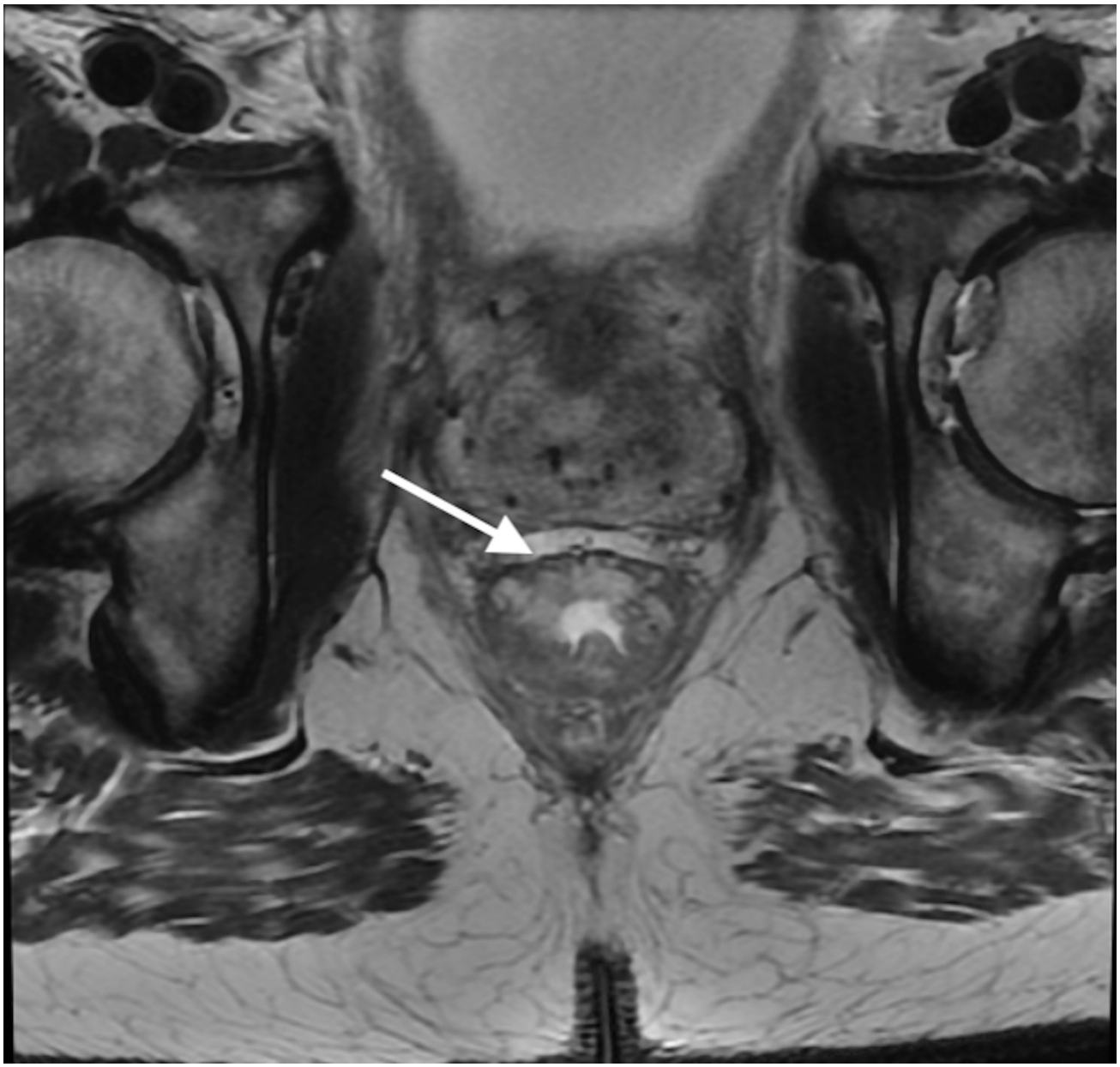
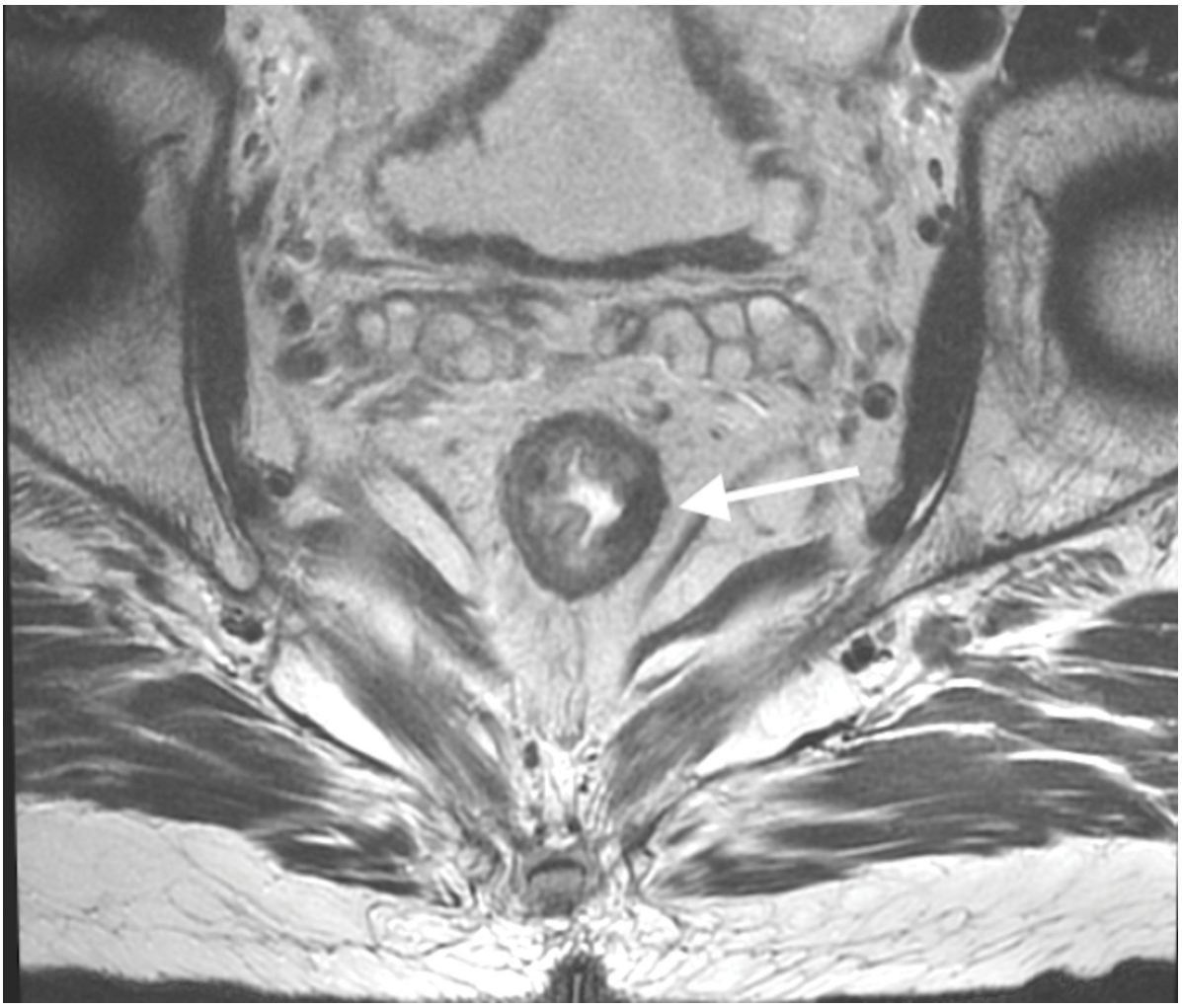


Figure 11.
T2W axial imaging. Note the markedly high signal of the anterior rectal tumor.



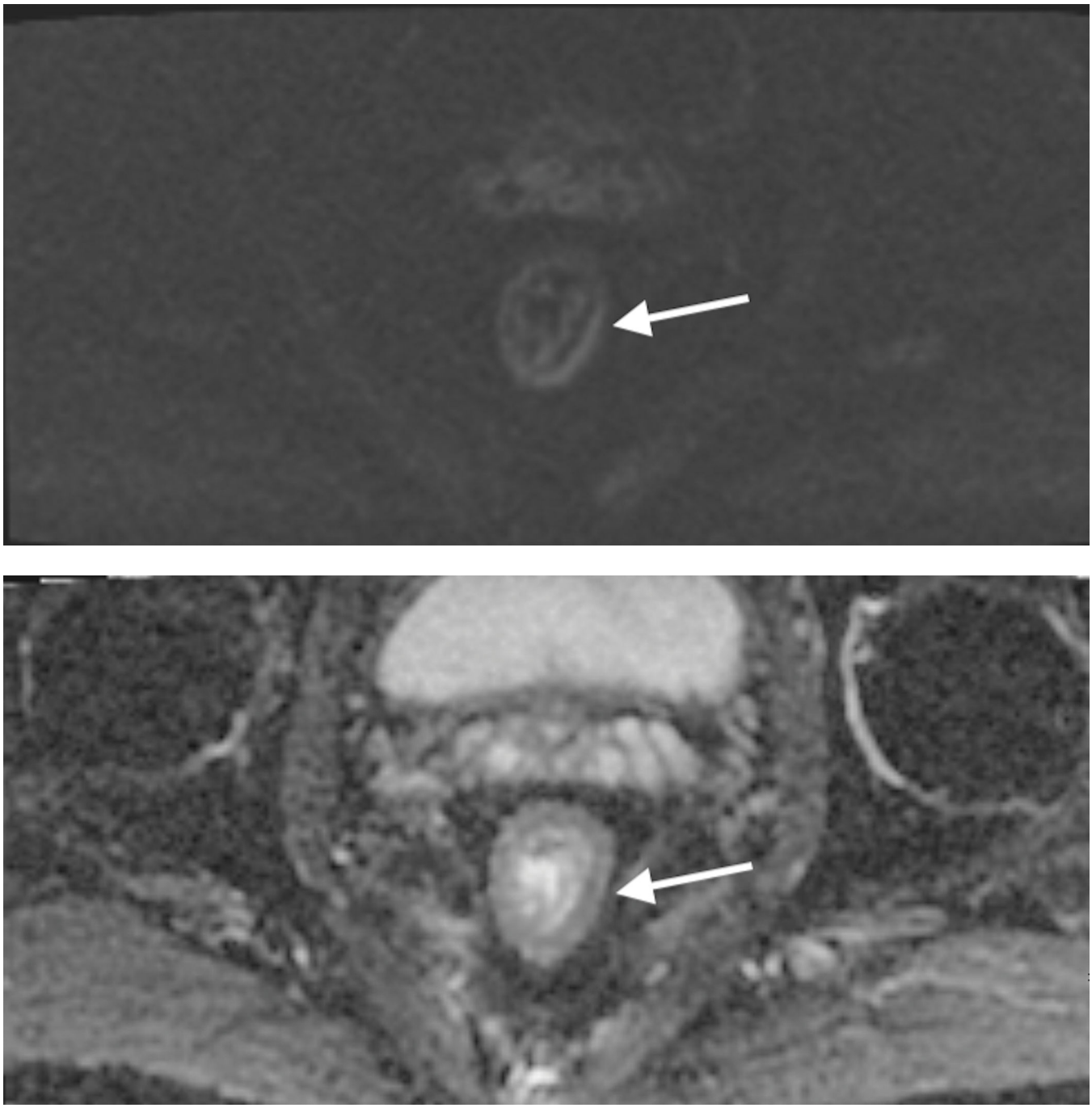


Figure 12.

Restaging MRI in a patient with complete response after chemoradiation. (A) Axial T2W, (B) DWI, and (C) ADC map shows a T2W dark scar in the left lateral rectal wall with no focal restriction diffusion.

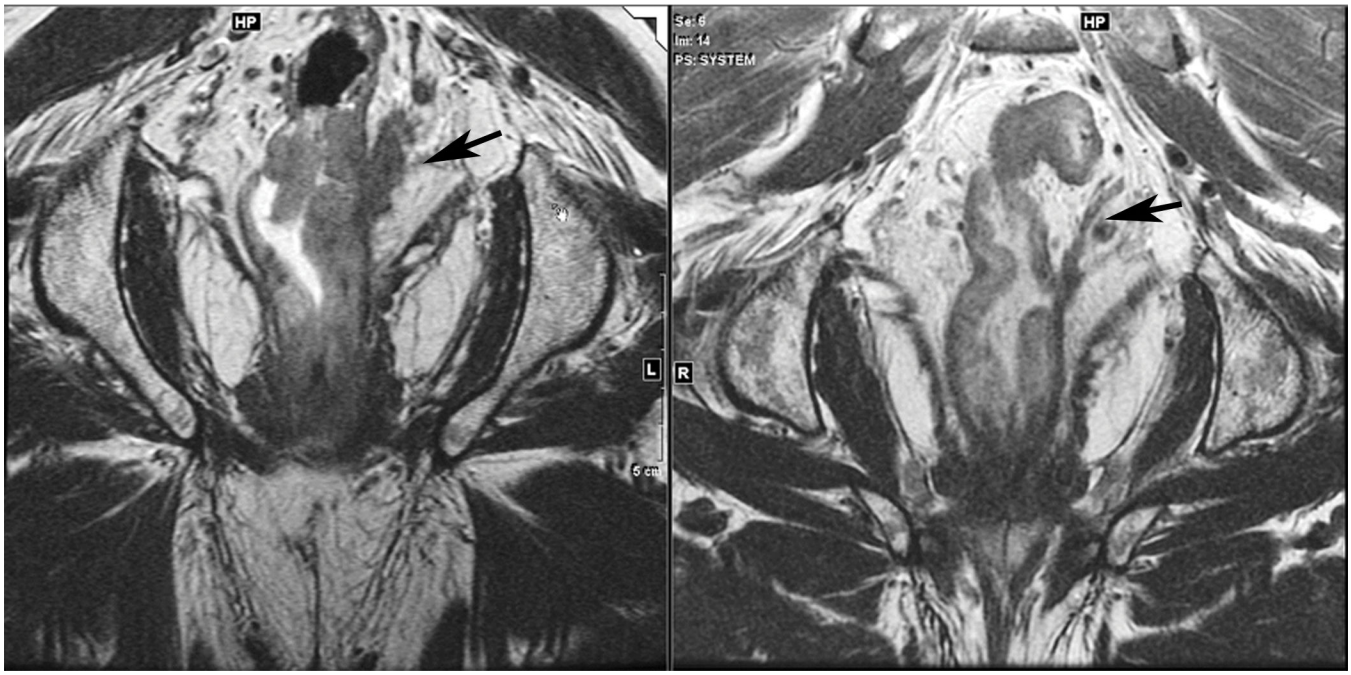


Figure 13.
Coronal T2W pelvic MRI (A) pre and (B) post treatment in a 45 yr. old male with rectal cancer. The left sided EMVI is smaller and T2 darker indicating at least partial regression.

Table 1.

Main similarities and differences between the most recent guidelines published by the European Society of Gastrointestinal and Abdominal Radiology (ESGAR) and the North American Society of Abdominal Radiology (SAR).

Similarities	
• MRI should be used for rectal cancer primary staging and restaging.	
• Endorectal ultrasound is recommended to differentiate between T1 and T2 tumors.	
• Minimal field strength requirement for the MRI system is 1.5 T.	
• 3 orthogonal planes T2W (sagittal, plus axial and coronal angulated to the tumor axis).	
• Coronal T2W parallel to anal canal in distal tumors.	
• Optimal slice thickness for T2W is 3 mm (ESGAR) and up to 3–4 mm (SAR)	
• DWI is recommended for restaging.	
• T1 and contrast images are not recommended.	
• MRF involved when distance between the tumor and MRF is < 1 mm	
• CR can be diagnosed when two-layered rectal wall is normalized on restaging.	
• Using *only* size threshold for LN staging is not universally accepted	
Differences	
SAR	ESGAR
• Measurement (mm) of the extent of tumor invasion beyond the bowel wall should be reported. • No consensus on the use of size criteria in primary staging of lymph nodes. • After CRT, nodal downsizing is considered a sign of sterilization.	• Only the discrimination between T3ab (<5 mm) and T3cd (> 5mm) is required regarding the extramural extension depth. • Nodal size criteria, depending on the morphological features. • After CRT, nodes with a short axis < 5 mm are considered sterilized.

Table 2.

T2W coronal plane to anal canal and different levels of anal involvement.

T2W coronal plane to anal canal	Level of anal involvement
	Tumor extends to the level of the internal sphincter but the muscularis propria of the rectal wall is intact with a fully preserved hypointense outer muscle coat. (MERCURY II; LEVEL 1)
	Tumor also invades internal anal sphincter but interrupts the hypointense muscle coat without extension into the intersphincteric plane. (MERCURY II; LEVEL 2)
	Tumor invades the intersphincteric space without involvement of the external anal sphincter/levator/puborectalis. (MERCURY II; LEVEL 3)
	Tumor also invades the external anal sphincter and levator ani muscles. (MERCURY II; LEVEL 4)