Diffusion weighted MR imaging of rectal cancer

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Learning objectives

1. Review the indications for MR imaging of rectal cancer

2. Describe the physics of MR diffusion weighted imaging (DWI) and describe a standard protocol for imaging rectal cancer.

3. Highlight the benefits of diffusion weighted imaging in assessing primary rectal cancer with a series of clinical cases.

4. Review potential pitfalls of DWI and areas for further research.
Background

Introduction:

Colorectal cancer is the second most common malignancy in Western societies and the second leading cause of death related to cancer. There are approximately 35,000 new cases of colorectal cancer and 19,000 deaths per year in the United Kingdom. Ninety eight per cent of colorectal tumours are adenocarcinomas. Rectal cancer accounts for approximately half of colorectal cancers and has a slight male predilection. Its prevalence increases steadily after the age of 50 years.

Imaging plays a crucial role in the preoperative management of rectal carcinoma. Initial diagnosis is usually made by a combination of endoscopy and biopsy. Further staging is required to assess the depth of invasion of the tumour. Preoperative staging techniques for rectal cancer should allow identification of patients with (1) extrarectal spread who might benefit from preoperative radiation therapy, (2) patients with low rectal tumours with minimal or no sphincteral involvement who might be suitable for sphincter-sparing surgery and (3) patients with very superficial lesions who may be suitable of endoscopy surgery (TEMS - transanal endoscopic microsurgery).

The extent of extrarectal spread is essential to stratify cases into those who would benefit from short course radiotherapy (usually T2 and some T3 tumours) and those who will need a long course neoadjuvant chemoradiotherapy therapy (bulky T3 tumours and T4 lesions). MRI is a well established technique for local staging of rectal cancer.

The use of MR diffusion weighted imaging (DWI) for the prediction and monitoring of disease response in colorectal cancer has been previously investigated for both primary disease and metastatic disease to the liver and recently DWI has been used to predict early disease response to neoadjuvant treatment of rectal cancer. The use of DWI in primary staging is evolving. Below the basics of DWI is explained.

Diffusion weighted imaging:

DWI explores the random motion of water in molecules in the body. Water movement in an unrestricted environment (e.g. in a container of water) is completely random, known as Brownian motion or free diffusion. By contrast, the movement of water in molecules in biologic tissues is limited by interactions with cell membranes and macromolecules.
The degree of restriction is inversely correlated to the tissue cellularity and the integrity of the cell membranes. The movement of water molecules is more restricted in tissues with a high cell density and intact cell membranes (e.g. tumours) (diagram 1 on page ). Tissues with lower cell density have a larger extracellular space and enable water molecules to diffuse more freely (diagram 2 on page ). The differences in tissue water diffusion capacity are exploited in diffusion weighted imaging.

Stejskal and Tanner initially described the first DWI sequence in 1965 as an adaption of an adapted T2 weighted sequence. DWI has been used extensively in brain imaging for the past 20 years. Recent advances in MR imaging have enabled diffusion imaging to be used in body imaging, including stronger diffusion gradients and faster imaging gradients. The standard technique is an ultrafast spin-echo echoplaner T2 weighted sequence.

As with standard spin echo T2 weighted imaging, a 90° radiofrequency (RF) pulse is applied followed by a 180° RF pulse (sequence 1 on page ). Water diffusion is measured by application of a dephasing gradient prior to the 180° RF pulse. A rephasing pulse is then applied immediately after the 180° RF pulse (sequence 1 on page ). In tissue with high cellularity (restricted water diffusion), the dephasing and rephasing pulses essentially cancel each other out and there is no significant impact on the overall T2 decay. In tissue with low cellularity, (unrestricted water diffusion), the water molecules may move a considerable distance between the dephasing and rephasing pulse. Therefore the water molecules may not be fully rephased, resulting in a reduction in the overall T2 signal.

The $b$ value refers to the strength of the diffusion sensitizing gradient. It is proportional to the gradient amplitude, the duration of the applied gradient and the time interval between paired gradients. Small $b$ values result in loss of signal in highly mobile tissues such as vessels or the bladder. As the $b$ value increases, less mobile water losses signal however water molecules in highly cellular tissues retain their high signal. DWI is rapidly expanding in MR body oncology imaging. It potentially allows functional characterization of primary tumours, detection of metastases as well as a technique to measure disease response to treatment.

**Protocol for DWI imaging of the rectum:**

Our basic sequence protocol for MR imaging of the rectum consists of T1 and T2-weighted fast spin echo sequences on a 1.5-T MR imager (Signa Excite; GE Medical Systems, Milwaukee, Wis) using the phased-array torso coil. Standard T2W imaging is performed in the coronal, axial and sagittal plane of the pelvis with axial high-resolution T2-weighted imaging performed through the rectum (thin-section (3mm) imaging, FOV
The T1-weighted imaging is an axial fast spin echo sequence of the pelvis. Buscopan (Boehringer Ingelheim Ltd UK) is administered to reduce motion artefact.

Axial DWI is performed with a single-shot echo-planar imaging sequence. A b value of 0 and 800 sec/mm$^2$ is ideal. Standard sequence parameters as follows; TR 8000ms, TE 100 ms ETL 1, Matrix 160 x 160, FOV 260 x 260 mm, NSA 4.

**Image interpretation:**

All cases are reviewed on a picture archiving and communication system workstation with standard correlation tools to correlate abnormalities on DWI and standard T2W sequences. The cases in the imaging review represent our institutions first 2 years experience with DWI of the rectum. We highlight areas where diffusion has been useful and possible pitfalls. The work forms part of study assessing DWI in primary rectal cancer staging.

Below is the up to date AJCC staging system which is referred to in the text.

**AJCC (TNM) Staging System for rectal cancer**

**T1:** The cancer has grown through the muscularis mucosa and extends into the submucosa.

**T2:** The cancer has grown through the submucosa and extends into the muscularis propria (outer muscle layer).

**T3:** The cancer has grown through the muscularis propria and into the subserosa but not to any neighboring organs or tissues.

**T4:** The cancer has grown through the wall of the colon or rectum and into nearby tissues or organs.

**Nx:** No description of lymph node involvement is possible because of incomplete information.

**N0:** No lymph node involvement is found.

**N1:** Cancer cells found in 1 to 3 nearby lymph nodes.

**N2:** Cancer cells found in 4 or more nearby lymph nodes.
Imaging findings OR Procedure details

The cases presented represent our unit’s initial experience with Diffusion Weighted Imaging (DWI) of the rectum. The imaging review highlights areas where DWI has been found to be useful and how it has affected tumour staging. Where possible, cases have been correlated with pathological findings.

Please use links to figures in text rather than the sidebar.

Assessment of Primary Tumour:

All cases where an MR rectum is performed to assess a rectal tumour have a biopsy confirmed diagnosis of adenocarcinoma. In Figure 1 and 2 there is a polypoid tumour in the distal rectum. The stalk of tumour is seen anteriorly (arrow). The tumour site is confirmed as the diffuse high signal intensity lesion seen on DWI in figure 2 (P-prostate T-tumour). Although DWI does not significantly alter staging in this case, the tumour is immediately obvious and shown to be confined to the muscularis. Figure 3 and 4 (axial T2W and DWI) show a more extensive tumour with invasion of the perirectal fat.

A posterior low rectal tumour is seen in Figure 5 and 6. On the initial T2W imaging, there is possible breach of the posterior rectal serosa (arrow), definite extension is confirmed on the DWI imaging with a spicule of tumour extending into the posterior perirectal fat.

Tumour extent - Differentiating T2 and T3 lesions with DWI:

DWI has been useful in confirming or excluding tumour extension into subserosa (differentiating T2 and T3 lesions).

In Figure 7,8 and 9, there is a large mid rectal tumour with obvious tumour spicules extending into the surrounding fat (T3 lesion). This can be seen on the coronal and axial T2W imaging (figure 7 and 8, arrow). Extension is confirmed on the DWI (figure 9 arrow).

There is low rectal tumour in Figure 10 and 11. On the T2W axial imaging, there is possible T3 extension along the right lateral margin (arrow) of the rectum, however the tumour is confined within the muscularis mucosa (T2) on the DWI sequence (figure 11, arrow). This was confirmed as a T2 lesion on histology.
A low rectal tumour is present on the sagittal T2W imaging (figure 12). The inferior margin of the tumour is difficult to assess on the axial T2W imaging (figure 13) however on DWI (figure 14), the inferior margin can be well demarcated. Figure 12, 13 and 14. Exact delineation of the inferior tumour extent is useful in assessing possible sphincter preserving surgery (Anterior resection versus Abdominoperineal resection).

Figure 15 and 16 show a high rectal lesion (circle). The lesion appears to breach the serosa along the left lateral margin, this is confirmed on the DWI sequence and extension is also noted along the right lateral margin (figure 16, arrow).

Figure 17 and 18 show a low rectal lesion posteriorly. The tumour certainly extends into the perirectal fat posteriorly in figure 17 but the DWI sequence shows extension into the levator complex.

We have found DWI most useful in differentiating T2 and T3 lesions.

Lesions that are difficult to detect on standard sequences:

Certain lesions can prove difficult to see on standard sequences, usually related to their small size. DWI can be invaluable in finding these lesions.

The lesion in figure 19 was missed on initial review of imaging. A small lesion is identified on the DWI sequence (figure 20), which correlated with the lesion seen at endoscopy. Figure 19 and 20

In figure 22 there is a small high signal intensity area on DWI in the posterior rectum, correlating with an endoscopically resected T1 lesion. Even with correlating the DWI, the lesion is almost invisible on standard T2W imaging (figure 21). Figure 21 and 22

Lesions on a corner

The lower sigmoid colon and proximal rectum can be highly tortuous. Lesions that occur on corners can be difficult to evaluate where the start and end of the lesion occur and whether there is subserosal extension. The DWI can be helpful in assessing the length of the tumour and possible extension when they occur on corners. These cases are difficult to fully appreciate on static images and are best seen on a workstation with side by side correlation.
There is an extensive lesion in figure 23, extending from the distal sigmoid colon into the rectum. The DWI is useful in assessing overall length of the tumour. Figure 23, 24, 25 and 26

The lesion in figure 27 and 28 (axial T2W) appears to be extensive however it is difficult to be sure exactly where it begins and ends, the DWI sequence correlates well with the standard T2W imaging and the DWI (figure 30) shows the inferior portion of the lesion is strictured. Figure 27, 28, 29 and 30

**Nodules / nodes in the circumferential resection margin (CRM)**

Delineation of nodules and nodes in the (CRM) is a difficult problem. The larger the nodule, the more likely it is to represent tumour. Smaller nodules are often indeterminate and could either represent tumour involved nodes or reactive nodes. Assessment of these nodes with DWI is an evolving area of interest. Correlation of these nodules with pathology is difficult and time consuming requiring evaluation of the entire en-bloc resection. The following cases have pathological correlation and had not undergone neoadjuvant therapy.

There is an obvious nodule posterior to the rectum in Figure 31 and 32. The DWI confirms the suspicious nodule seen on T2W imaging. This nodule was confirmed as tumour on post operative histology.

An eccentric tumour (arrow) is present in figure 33 with an indeterminate nodule in the CRM laterally (broken arrow). The DWI sequence (figure 34) shows a corresponding high signal intensity nodule in the CRM that was histologically confirmed as tumour (broken arrow Figure 33 and 34).

A tumour is seen posteriorly in the lower rectum. The tumour is high signal intensity on DWI. On standard axial T2W imaging, there is an indeterminate nodule in the CRM (Figure 35 and 36). On DWI there are multiple nodules in the CRM.

Studies are ongoing to assess the utility of DWI at assessing local disease within the CRM.

**Differentiation tumour from artefact / faecal material**

Synchronous tumours are not uncommon in colorectal cancer. Faecal material in the rectum can appear like eccentric tumour and we have found DWI useful in differentiation.
In figure 37, there is a possible posterior lesion in the rectum in a patient with a known rectosigmoid lesion. The lesion is not high signal on DWI and shown to be faeces on colonoscopy. Figure 37 and 38. A similar abnormality is seen in figure 39, which is negative on DWI and proved to be faeces. Figure 39 and 40. Care must be taken when interpreting DWI negative lesions as tumours of low cellularity may not be seen on DWI (please see pitfalls below).

**Malignant bone lesions**

Bone lesions are an uncommon finding in presenting rectal cancers however a number of lesions have been noted on DWI sequences which were not appreciated on standard sequences.

In figure 41, a tumour is noted in the low rectum. The tumour is also seen on DWI (figure 42, arrow) however a high signal intensity abnormality is seen in the right ischium (dotted circle). In retrospect it is just visible on the T2W imaging however a very difficult call. A CT scan 2 months later (figure 43) also shows the bone lesion. Figure 41, 42 and 43.

An extremely low rectal tumour in noted in figure 44. A DWI (figure 45) at the same level shows multiple lesions in the right inferior pubic ramus, a large tumour and an enlarged left inguinal lymph node. Figure 44 and 45.

In figure 46, a low rectal tumour is seen. On DWI (figure 47), the tumour is also noted as well as a lesion in the ischium (dotted circle). The bone lesion is also seen on a follow up CT scan (figure 48). Figure 46, 47 and 48.

**Recurrent disease**

Assessment of recurrent rectal cancer is a difficult because differentiating post operative scarring from recurrent tumour is problematic. Our initial experience with DWI is promising.

In figure 48, a normal anastomosis is seen. Anastomosis are normally high signal on DWI with a linear conformity (figure 49). Inferior to the anastomosis an area of soft tissue thickening is noted in the rectum (figure 50 arrow), this was high signal on DWI and confirmed as recurrent disease on DWI (figure 51 arrow). Figure 48, 49, 50 and 51.

In figure 52, a mass is seen in the rectum. The patient had a previous rectosigmoid tumour which was operated with a Hartmann's procedure. In figure 52 and 54, an ill defined
mass is seen in the apex of the rectal stump (arrow). It was unsure whether this was simply post op scarring. The lesion was of high signal intensity on DWI and confirmed as adenocarcinoma on histology Figure 52, 53 and 54.

Pitfalls

Although most rectal tumours are high signal on DWI, a certain percentage are not visualised. In figure 55, a tumour is seen in the low rectum, this was not visualized on DWI (figure 56). This may be the result of low cellularity within the primary lesions. This issue is undergoing further research Figure 55 and 56.

The artefact from hip replacements makes DWI sequences in the pelvis useless Figure 57 and 58.

It is essential to match all high signal intensity abnormalities on DWI sequences with an ADC map. In Figure 59, a tumour is seen in the mid rectum and a high signal nodule laterally (dotted circle). The nodule is of high signal intensity on DWI (figure 60). This is also high signal intensity on the ADC map. This represents T2 shine through from the left seminal vesicle Figure 59, 60 and 61. If the ADC map was noted assessed, one might think that this is a tumour nodule.
Fig. 0

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Fig. 0: Figure 1

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Conclusion

1. Diffusion weighting imaging is a useful adjunct to standard T2W sequences for local staging of rectal cancer. DWI allows characterization of (1) tumour location, depth and extent; (2) nodules / nodes within the circumferential resection margin; (3) identification of occult bone metastases; (4) assessment of recurrent disease.

2. Further research is required to assess why some lesions cannot be visualized on DWI, in particular correlation of tumour density with DWI signal.

3. This educational exhibit did not review DWI in assessment of treatment response post chemoradiotherapy which is an evolving area of research and of great interest.
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