SHORT COMMUNICATION

MR vs CT imaging: low rectal cancer tumour delineation for three-dimensional conformal radiotherapy

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ABSTRACT. Modern three-dimensional radiotherapy is based upon CT. For rectal cancer, this relies upon target definition on CT, which is not the optimal imaging modality. The major limitation of CT is its low inherent contrast resolution. Targets defined by MRI could facilitate smaller, more accurate, tumour volumes than CT. Our study reviewed imaging and planning data for 10 patients with locally advanced low rectal cancer (defined as < 6 cm from the anal verge on digital examination). Tumour volume and location were compared for sagittal pre-treatment MRI and planning CT. CT consistently overestimated all tumour radiological parameters. Estimates of tumour volume, tumour length and height of proximal tumour from the anal verge were larger on planning CT than on MRI ($p < 0.05$). Tumour volumes defined on MRI are smaller, shorter and more distal from the anal sphincter than CT-based volumes. For radiotherapy planning, this may result in smaller treatment volumes, which could lead to a reduction in dose to organs at risk and facilitate dose escalation.

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Radiotherapy is a critical component in the multi-disciplinary management of rectal cancer. Its role has been established in a spectrum of clinical settings, including pre-operative short-course radiotherapy, pre-operative chemoradiotherapy (CRT) and as post-operative therapy, though the last is now relatively unusual. These approaches may result in a reduction in the rate of pelvic recurrence, by virtue of negative surgical margins and sterilisation of nodal micrometastases in the pelvic side-wall, or a downstaging effect which may facilitate sphincter-sparing surgery. However, these benefits come at the price of acute and late normal tissue toxicities.

Pelvic radiotherapy usually causes some degree of acute toxicity, such as diarrhoea, proctitis, bladder irritation and skin effects. Late effects, or those side-effects occurring more than 1 month following completion of radiotherapy, include impotence, small bowel injury, delay in perineal wound healing and sphincter effects; the last was especially noted in those patients in whom irradiation of the anal sphincter to full dose was required [1, 2]. These effects are volume and dose dependent [3–6].

CT planning optimises dose delivery to a target volume with computerised dosimetry while respecting dose constraints to organs at risk (OAR). The major limitation of CT is its low inherent contrast resolution,

making distinguishing detail, such as the layers of the rectal wall and sphincter complex, very difficult. Thus, while other imaging modalities such as MR may be referenced by the clinician, the gross tumour volume (GTV) is defined on CT, with its inherent limitations.

Dual phased-array, thin-section MRI has been shown to be the gold standard for rectal cancer staging, with sensitivities of 71–91% and specificities of 78–100% [7–10]. MRI-defined tumour volumes for radiotherapy planning of rectal cancer could result in smaller, shorter, more accurate tumour contours, lying further from the anal sphincter. This would facilitate dose sparing to the sphincter and other low-lying normal tissues, for radiotherapy planning, especially if a “boost” is given based on the GTV. The aim of this study was to measure the differences in tumour dimensions on MR and CT images in patients with rectal cancer.

Methods and materials

Study population

Imaging and planning data for 10 patients with low rectal cancer (defined as < 6 cm from the anal verge on digital examination) were acquired retrospectively from patients within the EXPERT study [11]. This prospective study involved a neoadjuvant strategy of induction capecitabine/oxaliplatin prior to CRT with concomitant capecitabine and total mesorectal excision (TME) with adjuvant capecitabine for locally advanced rectal cancer.

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Eligible patients were defined on MRI as having: T3 tumours deemed to require abdominoperineal excision or T4 tumours or T3 tumours with a "threatened" circumferential resection margin (CRM). A threatened CRM is defined as tumour or nodal disease on MRI at or within 1 mm of the mesorectal fascia, the boundary of dissection for total mesorectal excision. Table 1 shows the demographic data of the patients in this study.

Imaging

Patients underwent planning CT in the prone position and then immediately in the supine position. An anal marker was placed for both positions. Patients drank 750 ml of water over 1 h prior to planning CT. Radiotherapy was delivered in the prone position, with supine data sets for study purposes only. On a subsequent occasion, but within 2–3 weeks after the CT planning scan, patients had a T_2 MRI scan in the same position (supine, flat couch, same bladder preparation, laser alignment). Intravenous contrast was not used for either investigation. From the supine CT scan, tumour length, width, distance to anal verge, and other parameters related to pelvic bony anatomy (sacral promontory, coccyx and upper and lower margins of pubis) were measured by a radiologist (GB) using a central reformatted sagittal image (Figure 1, Table 2). Corresponding tumour measurements were acquired from the pre-radiotherapy MRI scan using equivalent sagittal supine images. For CT, the position of the anal verge was based upon the anal marker.

Pre-radiotherapy supine T_2 MR scanning was performed on a 1.5-T Siemens scanner (Siemens AG, Erlangen, Germany) with a four-element pelvic phased-array wrap-around surface coil. All CT and MRI used thin slices (0.25 cm) through the entire pelvis, down to and below the anus. MR images were imported (Pinnacle TPS, version 7.4f, Philips Medical Systems, Andover, MA) for determination of tumour volume and the above parameters. Fusion of CT and MR data sets was not attempted. All measurements were determined with a tool within the treatment planning system.

Table 1. Patient demographics

	Males (<i>n</i> = 6)	Females (<i>n</i> = 4)
Mean age (years)	63	61
<i>Clinical fixity</i>		
Mobile	2	0
Tethered	3	4
Fixed	1	0
<i>MRI stage</i>		
T3a–dN0M0	0	0
T3a–dN1–2M0	3	4
T3a–dN1–2M1	2	
T4N1–2M0	1	
<i>Histological stage</i>		
ypT0N0M0	1	1
ypT2–3N0M0	1	1
ypT3N1–2M0	2	2
ypT4N0M0	1	

"yp" refers to the pathological stage following pre-operative therapy.

Statistical analysis

The mean, median and standard deviation were calculated for each pair of measurements. The 95% confidence interval for each pair was found using a paired *t*-test. The data were also analysed using the Wilcoxon signed-rank test, which tested whether each set of differences was significant. Multiple test adjustment lowered the comparison threshold to 0.05 to allow for running multiple *t*-tests, and so lowered the likelihood of achieving a significant result by chance.

Results

There were six male and four female patients. Mean ages were 63 years and 61 years, respectively. Abdomino-perineal excision (APE) was performed for all patients following pre-operative CRT.

CT and MRI tumour measurements are shown in Table 3. CT and MRI took place within a 2- to 3-week interval for all patients. CT consistently overestimated tumour dimensions. These differences were significant for tumour length, the height of the proximal tumour to the anal verge, tumour width and tumour volume (all $p < 0.05$; Table 3). The differences between these parameters remained significant using the Wilcoxon signed-rank test. Using multiple test adjustment, the differences between CT and MRI measurement of tumour volume, tumour length and height of proximal tumour for anal verge were highly statistically significant ($p < 0.005$). The mean difference in tumour volume was 18 cm³ greater on CT than on MRI. Similarly, the mean tumour length, maximum width and height of the proximal tumour from the anal verge were, respectively, 3.23 cm, 0.48 cm and 2.93 cm greater for CT measurements than for MR measurements. Figure 2 shows the differences in tumour morphology and volume seen on a CT scan and MR image in the same patient.

Discussion

Three-dimensional CT-based radiotherapy planning allows dose distributions to be highly "conformal" to a target. This has the advantage of sparing normal tissues and, consequently, normal tissue late effects, or permitting an escalation of the target dose for the same normal tissue exposure, or both. However, these strategies are heavily reliant upon accurate target delineation to be clinically meaningful. CT is the cross-sectional imaging method of choice for radiotherapy planning. CT is ideal for this purpose, as it gives anatomical tumour information with the electron density data essential for dosimetry. However, low inherent contrast resolution limits accurate tumour volumes. A rectal cancer GTV on CT may have the appearance of an amorphous grey mass while, in contrast, the superior contrast resolution of MR reveals detail such as rectal mucosa and muscularis and peritoneum for the same GTV.

The dimensions of a tumour, assessed by different imaging modalities, may not be equivalent and there may be consistent over- or underestimation of tumour volume. For example, for high-grade gliomas, clinical

Figure 1. Sagittal reformatted CT showing a T3 rectal adenocarcinoma (shaded area) with illustrated measurements from Table 2.

target volume and planning volumes are, respectively, 27% and 10% smaller when delineated from MRI than from CT [12]. To our knowledge, this study is the first comparison for tumour volumes for rectal cancer.

This study clearly demonstrates that CT significantly and consistently overestimates rectal tumour volume and the width, length and height of low rectal cancers from the anal verge, compared with the same measurements defined on MR. As expected, MR-defined tumour volumes for radiotherapy are smaller and further from the anal sphincter, and therefore MRI of tumour volumes for radiotherapy is likely to contribute to the sparing of normal tissues.

Pelvic organs at risk of radiation damage include bladder, bowel, ovary, uterus, testes, penile bulb and anal sphincter. These organs have dose-dependent toxicities [3–6]. Sphincter/pelvic floor dysfunction may be considered the predominant dose-limiting toxicity for low-lying rectal tumours. Sphincter dysfunction is dose and volume dependent, and remains a major challenge

for patients and clinicians [3, 4]. The extent of radiotherapy-induced sphincter morbidity is illustrated by the Dutch Colorectal Cancer Group randomised trial [1]. This trial randomised patients with operable rectal cancer of all stages to TME alone or pre-operative “short-course” radiotherapy of 25 Gy in five fractions over 1 week, followed by TME the following week. Within the radiotherapy arm, faecal incontinence for soiling once a week or less was as high as 62%, *vs* 38% for surgery alone ($p < 0.001$), and 14%, *vs* 5% for incontinence every day (no p -value given). Pad wearing, anal blood and mucus loss, satisfaction with bowel function and impact of bowel dysfunction on activities of daily living were significantly worse in the combined arm. Although this study relates to patients treated with APE following pre-operative CRT, smaller and more accurate GTV delineation will probably result in reduced irradiation of anal sphincter for patients who will undergo sphincter-sparing procedures.

Table 2. Parameters (cm) measured on the supine CT scan and MR image, from the sagittal view

Length of tumour	Proximal edge of the tumour (a)
Height from the anal verge to the:	Distal edge of the tumour (b)
Distance from proximal edge of the tumour to the:	Sacral promontory (c)
	Coccyx (d)
	Upper margin of the pubis (e)
	Lower margin of the pubis (f)
Distance from the distal edge of the tumour to the:	Coccyx (g)
	Upper margin of the pubis (h)
	Lower margin of the pubis (i)
The maximum width of the rectal tumour (j)	
The volume of the rectal tumour (cm ³)	

The letters in brackets denote the measurement line on Figures 1 and 2.

Table 3. Statistical differences between CT and MRI measurements using the paired *t*-test

Parameter measured (units)	Mean difference (ranges)	Standard deviation	Standard error of the mean	<i>p</i> -Value
Length of tumour (cm)	3.23 (CT 3.5–10.5; MR 0.41–4.1)	1.18	0.37	0.000
Maximum width of tumour (cm)	0.48 (CT 0.95–3.8; MR 0.9–3.96)	0.68	0.21	0.050
Volume of tumour (cm ³)	18.09 (CT 6.9–83.9; MR 1.07–54.17)	14.25	4.51	0.003
Height of proximal tumour to anal verge (cm)	2.93 (CT 6.9–14.28; MR 4–11.2)	2.25	0.71	0.003
Height of distal tumour to anal verge (cm)	0.12 (CT 1.9–9.9; MR 2.3–8)	1.64	0.52	0.816
Distance between proximal tumour and sacral promontory (cm)	0.59 (CT 5–11.5; MR 4.7–11.9)	2.16	0.68	0.413
Distance between proximal tumour and coccyx (cm)	0.27 (CT 2.9–6.2; MR 2–6.54)	1.42	0.45	0.556
Distance between proximal tumour and upper pubis (cm)	0.26 (CT 5.4–12.9; MR 7.7–15.12)	2.75	0.87	0.770
Distance between proximal tumour and lower pubis (cm)	0.42 (CT 5.5–11.5; MR 5–12.04)	3.07	0.97	0.675
Distance between distal tumour and coccyx (cm)	0.27 (CT: 2.8–6.9; MR: 1.8–5.8)	1.17	0.37	0.482
Distance between distal tumour and upper pubis (cm)	0.17 (CT 6.5–13.4; MR 7–17.5)	2.77	0.88	0.849
Distance between distal tumour and lower pubis (cm)	0.66 (CT 4.5–12.6; MR 3.5–11.4)	1.42	0.45	0.179

Although superior contrast resolution of MR over CT is well recognised for a number of tumour sites, it is difficult to replace CT as the primary radiotherapy planning imaging modality. The reasons for this are twofold: MR image distortion and the lack of electron density information for dosimetry. Accurate geometric data are essential for radiotherapy planning and, therefore, image distortion can be a real obstacle in transferring to MR-based planning. However, distortions caused by the heterogeneity of the magnetic field and eddy currents can be minimised by shielded newer-generation MRI scanners. Superconducting MRI can also better facilitate patient positioning, so reducing the heterogeneity that occurs with MR the greater the distance from the centre of the magnet.

MR-based rectal tumour volumes are smaller and more accurate, and thus lie further from the anal verge, facilitating relative sparing of the anal sphincter/pelvic floor for pelvic radiotherapy. Escalation of the dose higher than standard pre-operative levels (45–50 Gy) may cause a continued dose response for rectal cancer

[11, 13–15], leading to the addition of a Phase II ‘boost’, based on the GTV alone. This is especially important for those patients in whom downstaging is required to facilitate resectability [10], sphincter preservation, or non-operative management [16]. As Phase II boosts are more commonly incorporated in radiotherapy protocols for locally advanced rectal cancer, smaller and more accurate MRI-based GTV definition becomes increasingly relevant.

This study has inherent limitations, namely the need for supine planning, small numbers with very specific staging, and GTV delineation by a skilled diagnostic radiologist. Patients usually receive pelvic radiotherapy in the prone position, such that the small bowel may gravitate outside the radiotherapy volume. However, the volume of the bowel receiving higher dose levels is not significantly higher in the supine than in the prone position [17]. The rectal cancers in this series are very locally advanced, reflecting the eligibility within the EXPERT trial [11]. However, GTV delineation with MR is very likely to significantly reduce GTV volume both for

(a)

(b)

Figure 2. (a) Axial CT and (b) axial T_2 fast spin-echo (TR 3900, TE 120) MR images from the same patient, showing a T3 rectal adenocarcinoma. The shaded areas represent gross tumour volume delineation by the same radiologist. This overestimation of tumour volume on CT was consistent for all patients.

prone planning and with less locally advanced rectal tumours. GTV delineation in clinical practice is usually performed by a radiation oncologist, though often in consultation with a diagnostic radiologist. The emergence of MR as a key component in radiotherapy planning presents a challenge to radiation oncologists.

This study has demonstrated that tumour volumes defined on MR images are smaller, shorter and more distal from the anal sphincter than CT-based volumes. For radiotherapy planning, this may result in smaller treatment volumes, which could lead to a reduction in dose to organs at risk, and facilitate dose escalation. This study is therefore the initial stage in a stepwise planning process for the integration of MRI into radiotherapy planning for rectal cancer. Future studies should further the experience of MRI in radiotherapy planning for rectal cancer, to assess how the use of MRI would result in differences to the target volume from that defined using the current technique and, if differences do occur, to examine the potential consequences in terms of predicted dose to organs at risk, such as bowel and anal sphincter.

Conclusions

CT consistently overestimates rectal tumour volume and the width, length and height of low rectal cancers from the anal verge, relative to the same measurements defined on MR. MR-defined tumour volumes are smaller and further from the anal sphincter, and therefore likely to contribute to sparing of normal tissues, especially the anal sphincter. Smaller and more accurate MR-based GTV definition may facilitate the addition of Phase II "boosts", based on the GTV alone, with acceptable sphincter morbidity.

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