Distortion-corrected $T_2$ weighted MRI: a novel approach to prostate radiotherapy planning

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ABSTRACT. The purpose of this study was to evaluate distortion-corrected MRI as a radiotherapy planning tool for prostate cancer and the resultant implications for dose sparing of organs at risk. 11 men who were to be treated with radical conformal radiotherapy for localized prostate cancer had an MRI scan under radiotherapy planning conditions, which was corrected for geometric distortion. Radiotherapy plans were created for planning target volumes derived from the MRI- and CT-defined prostate. Dose volume histograms were produced for the rectum, bladder and penile bulb. The mean volume of the prostate as defined on CT and MRI was 41 cm$^3$ and 36 cm$^3$, respectively ($p = 0.009$). The predicted percentage of the rectum treated to dose levels of 45–65 Gy was significantly lower for plans delineating the prostate with MRI than for those with CT. The rectal-sparing effect was confined to the lowermost 4 cm of the rectum (anal canal). There were no differences between the predicted doses to bladder or penile bulb (as defined using MRI) between plans. In conclusion, prostate radiotherapy planning based on distortion-corrected MRI is feasible and results in a smaller target volume than does CT. This leads to a lower predicted proportion of the rectum, in particular the lower rectum (anal canal), treated to a given dose than with CT.

CT represents the standard method of target localization in radical conformal radiotherapy for prostate cancer. CT is well-suited as a radiotherapy planning tool because it provides electron density data that are used for dosimetric planning. In addition, CT is free from geometric distortion, *i.e.* spatial information is faithfully represented to scale. CT is, however, limited by poor soft-tissue contrast such that, in the case of the prostate gland, the interface between the prostate and the pelvic floor muscles may be indistinct.

MRI offers superior soft-tissue contrast to CT, and comparisons between the two have shown that CT results in a probable overestimation in the size of the prostate and uncertainty as to the precise location of the apex of the gland, when compared with MRI [1–8]. This may have an impact on the radiation dose to organs at risk (OARs), in particular the rectum and penile erectile tissue [2, 8–10]. Definition of the prostate with MRI rather than CT could lead to sparing of these structures, with a consequent reduction in toxicity, and allow radiotherapy dose escalation.

The use of MRI as a radiotherapy planning tool has been hampered by the lack of direct electron density data available with MRI, and the presence of geometric distortion inherent in the technique. These issues must be addressed before MRI can replace CT as the imaging of choice for prostate radiotherapy planning. Bulk assignment of electron density data to MRI images is feasible, with dosimetric planning on such images resulting in only minor differences from CT [11]. Our group have described a method for correcting standard clinically available three-dimensional (3D) MRI images for patient-and system-based distortion [12–14]. In this study, we evaluate the practicality of using distortion-corrected MRI for target definition in prostate cancer radiotherapy planning, and the consequences in terms of the characteristics of the target volume and the predicted radiotherapy doses to OARs.

Methods and patients

The research protocol was approved by the Royal Marsden NHS Trust and Institute of Cancer Research Committee for Clinical Research and Regional Ethics Committee. Informed consent was obtained from each patient.

Eligibility

Eligible patients were those who were to undergo CT-planned radical conformal radiotherapy for carcinoma of the prostate, with no contraindications to MRI. Patients were required not to have had insertion of any metallic prostheses.

Received 9 March 2007
Revised 26 April 2007
Accepted 5 June 2007
DOI: 10.1259/bjr/51363812
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likely to degrade the CT and MRI images. 14 patients were recruited between December 2003 and June 2004.

**CT scanning**

Patients were scanned supine on a flat couch top with the arms folded on the chest. A foam headrest was used, and foam wedges were placed behind the knees. Ankle stocks were used to prevent rotation of the hips. In order to achieve a comfortably full bladder, patients were asked to empty their bladder on arrival in the department, and then drink 350 ml of water. The CT scan was performed 1 h later. No specific measures were taken to influence the degree of rectal filling. CT scanning was performed with a GE HiSpeed QX/i scanner (GE Healthcare Diagnostic Imaging, Slough, UK) using a 4×2.5 mm helical scan acquisition reformatted to 2.5 mm slice thickness.

**MRI scanning**

The same patient positioning was employed for MRI as for CT. A customized perspex couch insert (Figure 1) was used to achieve a flat scanning surface. Patients were asked to empty their bladder and then drink 350 ml of water. Scanning took place 30 min later, rather than 1 h as for CT, in order to take into account the longer MRI scanning time. Scanning was performed on a 1.5 T Philips Intera Gyroscan (Philips Medical Systems, Reigate, UK) employing a phased array wrap-around pelvic coil. The posterior part of the coil was positioned under the flat-topped couch, and the anterior part placed over the patient’s pelvis. In addition to standard clinical images, 3D $T_2$ weighted images were acquired with the following scan parameters: repetition time (TR)=3000 ms, echo time (TE)=120 ms, field of view (FoV)=400×300 mm, matrix=256×144 reconstructed to 256×192, slice thickness=2.5 mm, number of signal averages=1, 60–70 slices (individualized for full coverage of bladder and rectum), read bandwidth=651 Hz per pixel. To enable subsequent correction for distortion associated with magnetic field strength inhomogeneities, two sets of data were acquired with alternating positive and negative polarity read gradients [14].

**Distortion correction**

Geometric distortions result from system- and patient-based effects. System-based distortion arises from inhomogeneities in the main magnetic field (Bo) and from non-linearities in the applied magnetic field gradients. The presence of a patient within a scanner will further perturb the homogeneity of the main magnetic field, with the magnitude and geometry of this effect being specific to the individual patient. Subject-induced distortions arise from susceptibility and chemical shift variations within the individual patient and are of particular concern at fat/non-fat interfaces (chemical shift) and tissue/air interfaces (susceptibility).

The effects of both magnetic field inhomogeneities (system- and patient-based) and gradient non-linearities can be corrected retrospectively. Patients were scanned using a standard clinical 3D spin-echo sequence modified to acquire two sets of otherwise identical images: one acquired with a forward polarity read gradient and one with a reverse polarity read gradient. Corresponding features in the two sets of images were identified and their respective intensities and positions determined [14]. The images could then be corrected for the effects of distortion arising from magnetic field inhomogeneities (system- and subject-based) as a function of these intensities and positions [13, 14]. Gradient-based distortions associated with this sequence were mapped, quantified and subsequently corrected using a 3D test object of known linearity [12, 13].

**Image co-registration**

CT and distortion-corrected MRI images were transferred to a radiotherapy treatment planning system (Pinnacle 3; Philips Radiation Oncology Systems, Milpitas, CA). CT and MRI images were manually co-registered using bony anatomy. In all but one case, shifts of the MRI data set with respect to CT resulted in matching of the bony anatomy with good internal consistency. In one patient, a significant angulation of the pelvis on CT made matching difficult, and data from this patient were used only for volume comparisons.

**Target definition**

The prostate clinical target volume (CTV) was outlined by a radiologist (SAS) and clinical oncologist (ASNJ) working by consensus. For each patient, the CT images were outlined before the MRI, with a minimum interval of 1 week between the two. Readers were blinded to the other imaging modality when outlining.

**Definition of organs at risk**

The bladder, including the outer wall, and the anus/rectum, including the wall and contents from the ischial...
Dosimetric planning

Radiotherapy plans were generated for each patient from CT- and MRI-defined targets. MRI was used to define the dose volume histogram (DVH) for OARs. It was recognized that differences in rectal filling between MRI and CT could, in effect, move the prostate between scans, and that this might be expected to influence the predicted dose to the rectum. To minimize any influence on predicted dose to OARs from differences in rectal filling between the two scans for each patient, patients were included in the planning comparison only if there was less than a 50% difference between CT and MRI of the rectal antero-posterior (AP) diameter at the level of the mid-prostate (defined on CT). As a measure of the effect of rectal filling on the position of the prostate, the relative positions of the most anterior part of the anterior rectal wall between MRI and CT were noted.

As MRI greyscale data cannot be used directly for inhomogeneity correction, the MRI-defined CTVs and OARs were copied onto the corresponding CT. This allowed calculation of a plan based on the MRI-derived prostate contour, using the electron density data from CT. For the prostate, planning target volumes (PTVs) were generated, consisting of the prostate plus a 5 mm margin symmetrically. A margin of 5 mm was chosen to reflect the anticipated technological developments in prostate radiotherapy that may control for organ movement and allow such restricted margins. The volume of the CTV and PTV for both MRI and CT was recorded, as the length of the PTV in the cranio-caudal direction.

For each PTV, a three-field plan was generated using an anterior and two opposing wedged lateral fields. This is the standard field arrangement used in our department for prostate radiotherapy, and has been shown to be at least equivalent to arrangements using a greater number of fields in terms of rectal dose sparing [24]. For this exercise, blocks rather than a multi-leaf collimator (MLC) were chosen for beam shaping so that results were independent of MLC leaf width. A symmetrical block margin of 6 mm was used, with an additional 2 mm margin in the superior and inferior directions to account for penumbra.

The same field arrangement, wedge angles and beam weighting was used to cover the CT- and MRI-derived PTV within each patient. For an individual patient, the only difference between treatment techniques for the MRI- and CT-defined PTV was the field shape. For each plan, the PTV was treated to a notional dose of 70 Gy, representing the standard dose employed in our department at the time of the study, which was prescribed to the centre of the CT-defined PTV for each pair of plans. An adaptive convolution dose computation algorithm was used.

DVHs were generated from plans using CT- and MRI-defined target volumes and OARs as defined by MRI. For the rectum (as a whole, and also after separation into upper and lower parts) and the bladder, DVHs were expressed as the proportion of the whole structure receiving a given dose. For the penile bulb, DVHA were collected as the dose received by a given proportion of the structure. Maximum dose ($D_{\text{max}}$) and the mean dose were also collected. The penile bulb parameters were chosen from studies relating DVH data to erectile function [25–29].

Statistical analysis

Statistical analysis was carried out using SPSS (SPSS Inc, Chicago, IL) and Minitab (Minitab Ltd, Coventry, UK). Data were tested for normality using the Anderson–Darling test. Paired Student’s $t$-tests (two-tailed) were used for volume and DVH comparisons for normally distributed datasets; otherwise, a Wilcoxon signed rank test was used (most V70 values, and penile bulb data). A $p$-value of $<0.05$ was taken as representing statistical significance.

Patient characteristics

Patient characteristics are shown in Table 1. All patients received neo-adjuvant luteinising hormone-releasing hormone agonist therapy prior to radiotherapy as part of their routine clinical management. CT was performed after a median of 12 weeks of hormonal treatment (range 5–38 weeks). The MRI scan took place a mean of 3 days after the CT (range 0–8 days).

Results

Organ volumes

Mean organ volumes are shown in Table 2. This includes all 14 patients for the prostate, seminal vesicles and rectum. Three patients did not have complete inclusion of the dome of the bladder on the MRI scan, and were therefore excluded from any further analysis pertaining to the bladder. There was considerable variation in the volume of the rectum and bladder between MRI and CT for each patient, mainly representing differences in organ filling.

For the prostate, the MRI volume was smaller than the CT volume in 12 cases and larger in 2 (Figure 2). For the
13 cases in whom satisfactory co-registration between MRI and CT was achieved, the apex of the prostate was visualized as lying more inferiorly on CT than on MRI in seven cases (2.5–10 mm), 5 mm lower on MRI in one case, and the same in five cases. Overall, mean and median inferior displacement of the apex was 2.5 mm on CT compared with MRI. Bladder volume differences between CT and MRI were unrelated to prostate apex localization ($r = -0.0005$). There was no consistent difference between imaging techniques with regard to the AP position of the gland, which appeared to be more associated with the degree of rectal filling.

The mean and median distances, respectively, between the most inferior part of the prostate and the penile bulb were 11.6 mm and 12.5 mm for CT (range 5–17.5 mm) and 14.1 mm and 15 mm for MRI (range 5–20 mm) ($p = 0.08$), in keeping with the more caudal definition of the prostate apex on CT.

Two patients were excluded from the radiotherapy planning study on the basis of a greater than 50% difference in the AP dimension of the rectum at the level of the mid-prostate. There remained differences in the dimensions of the rectum between CT and MRI, and thus the position of the prostate for the remaining 11 patients. The mean difference between the position of the most anterior part of the rectal wall between MRI and CT was such that, on average, the anterior rectal wall at the level of the mid-prostate on MRI lay 0.3 mm anterior to that on CT (range, MRI 5 mm anterior to 9 mm posterior to CT; standard deviation, 3.85 mm)

**Radiotherapy plan comparisons**

11 patients were used for the radiotherapy planning study. Of the original 14 patients, one was excluded, as satisfactory co-registration of CT and MRI could not be achieved, and two were excluded on the basis of large differences between the rectal diameter on MRI and CT. The characteristics of the target volumes for the 11 patients are shown in Table 3. It was observed that copying an MRI-defined structure to CT resulted in a small increase in the volume of that structure of approximately 2%. This effect results from different voxel sizes between MRI and CT, which the planning software accounts for by rounding the volume to the nearest CT voxel. Bladder DVH data are presented for eight patients, having excluded those three with incomplete inclusion of the bladder on MRI. For the penile bulb, DVH data are presented for 9 patients, comprising those 11 used for the rectal comparison, but excluding 2 patients in whom the most inferior extent of the penile bulb was not imaged on MRI.

The minimum requirement that 100% of the target volume is encompassed by the 95% iso-dose line for adequate PTV coverage, as defined by the International Commission on Radiation Units, was met for all plans. DVH parameters for the whole rectum, upper rectum, anal canal and bladder from plans treating the prostate defined by CT and MRI are shown in Table 4. A lower proportion of the rectum was irradiated to doses from 45 Gy to 65 Gy ($p = 0.05$) using the MRI-derived plan. At these doses, 4–6% less of the rectum received a given dose with MRI when compared with CT. When the rectum was divided into upper and lower (anal canal) sections, there was a significantly reduced dose to the anal canal, but not the remaining rectum, using the MRI plan. There was no significant difference in the volume of bladder treated to any of the dose levels between CT and MRI. For the penile bulb, there was no significant difference in all but one (dose to 90% of the penile bulb) of the parameters examined.

### Table 2. Organ volumes

<table>
<thead>
<tr>
<th>Organ</th>
<th>Mean CT volume ± SD (cm³)</th>
<th>Mean MRI volume ± SD (cm³)</th>
<th>$p$-value (paired t-test)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prostate</td>
<td>38 ± 14.7</td>
<td>33 ± 13.8</td>
<td>0.009</td>
</tr>
<tr>
<td>Seminal vesicles</td>
<td>11.4 ± 4.2</td>
<td>7.8 ± 4.6</td>
<td>0.001</td>
</tr>
<tr>
<td>Rectum</td>
<td>91 ± 56.6</td>
<td>107 ± 75.9</td>
<td>0.551</td>
</tr>
<tr>
<td>Anal canal</td>
<td>–</td>
<td>13.6 ± 4.4</td>
<td>–</td>
</tr>
<tr>
<td>Upper rectum</td>
<td>–</td>
<td>82 ± 55.6</td>
<td>–</td>
</tr>
<tr>
<td>Bladder</td>
<td>296 ± 159</td>
<td>261 ± 112</td>
<td>0.328</td>
</tr>
<tr>
<td>Penile bulb</td>
<td>–</td>
<td>2.9 ± 0.72</td>
<td>–</td>
</tr>
</tbody>
</table>

MRI for prostate radiotherapy planning
CTV, clinical target volume; SD, standard deviation; PTV, planning target volume.

Results expressed as percentage of organ receiving given dose

<table>
<thead>
<tr>
<th>Mean</th>
<th>CT prostate</th>
<th>MRI prostate</th>
<th>p-value (paired t-test)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CTV ± SD (cm³)</td>
<td>41 ± 15.2</td>
<td>36 ± 14.7</td>
<td>0.016</td>
</tr>
<tr>
<td>MRI CTV copied onto CT ± SD (cm³)</td>
<td>-</td>
<td>37 ± 14.9</td>
<td>-</td>
</tr>
<tr>
<td>Mean PTV ± SD (cm³)</td>
<td>93 ± 25.3</td>
<td>81 ± 25.1</td>
<td>0.033</td>
</tr>
<tr>
<td>Mean PTV length ± SD (mm)</td>
<td>54 ± 8.9</td>
<td>53 ± 6.9</td>
<td>0.526</td>
</tr>
</tbody>
</table>

CTV, clinical target volume; SD, standard deviation; PTV, planning target volume.

**Discussion**

We found that the prostate CTV defined by distortion-corrected MRI was significantly smaller than with CT. Treatment plans using a 5 mm margin from CT to PTV showed a statistically significant reduction in the predicted proportion of the rectum treated to dose levels from 45–65 Gy using the plan derived from MRI. This effect was most apparent for the lower rectum (anal canal). We saw no difference in the dose to bladder or penile bulb between plans.

Other studies [1–10] have compared CT and MRI prostate definition, but few have attempted to quantify the differences between predicted doses to OARs [2, 6, 8, 9] and none has compared distortion-corrected MRI images with CT. Khoo et al [1] described how MRI provides improved definition of prostate treatment volumes compared with CT. The study examined a number of MRI sequences and scored them as to the ease of visualization of the prostate and other pelvic structures, but did not quantify or compare target volumes between imaging modalities.

Prostate volumes from published studies comparing CT and MRI are shown in Table 5. Roach et al [7] defined the prostate alone on CT and on MRI. The images were merged using bony landmarks. They found a reduction of 23% in the prostate volume with MRI CT most overestimated the posterior and inferior aspects of the gland.

Kagawa et al [10] outlined the prostate with and without the seminal vesicles of 22 patients on CT and MRI. Images were co-registered using bony landmarks. The average prostate volume was 63 cm³ and 50.9 cm³—a reduction of 19% with MRI. The prostatic apex lay 4.9 mm more cephalad and 1.4 mm dorsal on MRI than on CT, at a distance of 15.1 mm cephalad and 7.1 mm dorsal to the tip of the urethrogram cone.

In the study by Debois et al [9], 10 patients underwent CT as well as axial and coronal MRI scans. Images were mathematically aligned (the methodology was not described) and the prostate and rectum contoured using each modality by three observers. The prostate volume was smaller using MRI for 9 of the 10 patients studied. MRI gave a mean volume 28% smaller than CT. In all instances, the prostatic apex was defined more caudally, or the same, with CT when compared with MRI. The authors felt that coronal images were an essential adjunct to axial images on MRI in defining the prostatic apex. The posterior extent of the prostate gland and anterior rectal wall was better defined with MRI, and the volume of the rectum irradiated to 80% of the prescribed dose ($V_{rectum80%}$) was less using MRI than CT in 8 out of 10 cases, and greater in 2. For all patients, the overall difference in $V_{rectum80%}$ between CT and MRI did not reach statistical significance.

Sannazzari et al [2] outlined the prostate and seminal vesicles of eight patients using CT and MRI. Defining the prostate using MRI resulted in a volume reduction of 19% ($p<0.01$). A planning study suggested that it was possible to spare 10% of the rectal, and 5% of the femoral head and bladder, volumes from the radiation field

**Table 4. Dose volume histogram characteristics for the rectum, anal canal, upper rectum and bladder (defined by MRI) for plans treating the prostate defined by CT and MRI**

<table>
<thead>
<tr>
<th>Organ at risk</th>
<th>Modality used to define prostate</th>
<th>45 Gy</th>
<th>50 Gy</th>
<th>55 Gy</th>
<th>60 Gy</th>
<th>65 Gy</th>
<th>70 Gy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rectum including anal canal (n=11)</td>
<td>CT</td>
<td>23 ± 9.4</td>
<td>21 ± 9.1</td>
<td>19 ± 8.6</td>
<td>17 ± 8.1</td>
<td>14 ± 7.5</td>
<td>2 ± 3.3</td>
</tr>
<tr>
<td>MRI</td>
<td>18 ± 14.9</td>
<td>16 ± 4.4</td>
<td>15 ± 4.0</td>
<td>12 ± 3.3</td>
<td>8 ± 3.6</td>
<td>1 ± 0.6</td>
<td></td>
</tr>
<tr>
<td>p-value</td>
<td>0.047</td>
<td>0.048</td>
<td>0.037</td>
<td>0.035</td>
<td>0.043</td>
<td>0.097</td>
<td></td>
</tr>
<tr>
<td>Anal canal (n=11)</td>
<td>CT</td>
<td>42.8 ± 20.0</td>
<td>40.0 ± 19.5</td>
<td>37.4 ± 19.2</td>
<td>33.9 ± 18.1</td>
<td>28.4 ± 16.4</td>
<td>24.7 ± 13.5</td>
</tr>
<tr>
<td>MRI</td>
<td>33.4 ± 15.6</td>
<td>30.7 ± 15.3</td>
<td>27.9 ± 14.5</td>
<td>24.7 ± 13.5</td>
<td>20.0 ± 11.3</td>
<td>19.0 ± 11.3</td>
<td></td>
</tr>
<tr>
<td>p-value</td>
<td>0.013</td>
<td>0.014</td>
<td>0.016</td>
<td>0.045</td>
<td>0.015</td>
<td>0.021a</td>
<td></td>
</tr>
<tr>
<td>Upper rectum (n=11)</td>
<td>CT</td>
<td>16.6 ± 9.4</td>
<td>15.2 ± 9.1</td>
<td>13.9 ± 8.5</td>
<td>12.3 ± 8.1</td>
<td>9.7 ± 7.5</td>
<td>7.5 ± 6.4</td>
</tr>
<tr>
<td>MRI</td>
<td>13.7 ± 5.8</td>
<td>12.3 ± 5.2</td>
<td>10.9 ± 4.7</td>
<td>9.3 ± 4.1</td>
<td>6.8 ± 3.4</td>
<td>3.3 ± 0.7</td>
<td></td>
</tr>
<tr>
<td>p-value</td>
<td>0.145</td>
<td>0.149</td>
<td>0.115</td>
<td>0.110</td>
<td>0.126</td>
<td>0.208a</td>
<td></td>
</tr>
<tr>
<td>Bladder (n=7)</td>
<td>CT</td>
<td>23.0 ± 12.7</td>
<td>18.1 ± 9.2</td>
<td>16.0 ± 11.3</td>
<td>14.3 ± 7.7</td>
<td>10.6 ± 6.4</td>
<td>5.8 ± 5.1</td>
</tr>
<tr>
<td>MRI</td>
<td>24.6 ± 9.8</td>
<td>19.2 ± 7.6</td>
<td>17.2 ± 6.9</td>
<td>16.5 ± 5.5</td>
<td>11.7 ± 5.1</td>
<td>1.1 ± 1.6</td>
<td></td>
</tr>
<tr>
<td>p-value</td>
<td>0.423</td>
<td>0.485</td>
<td>0.347</td>
<td>0.484</td>
<td>0.286</td>
<td>0.732</td>
<td></td>
</tr>
</tbody>
</table>

Results expressed as percentage of organ receiving given dose ± standard deviation. p-values refer to paired t-tests between MRI- and CT-derived parameters except a (non-normal datasets), where the Wilcoxon signed rank test is used.
in summary, CT may overestimate the volume of the prostate compared with MRI, which can result in prostate volumes up to 40% smaller than with CT. Again, CT most overestimated the inferior and posterior extents of the gland. The apex of the gland as defined by MRI is reported to lie posterior and cranial to its apparent location on CT, a consistent finding in most studies but contradicting work by Milosevic et al [4], who found variation between MRI and CT in defining the apex but not consistently in any direction. This may have been as a result of the 1 cm slice thickness used for CT, which would be less able to detect sub-centimetre differences in apical position. In the current study, using a slice thickness of 2.5 mm for both imaging modalities, we have demonstrated a 13% reduction in the prostate volume using MRI when compared with CT. The reduction we saw with MRI was less than for much of the foregoing work; this may be as a result of the improved quality of CT images over recent years. Also, as described by Parker et al [5], experience with MRI may improve the interpretation of CT, modifying and reducing the volume of prostate outlined.

We found that the prostatic apex tends to be located more caudally on CT than on MRI, in keeping with the majority of published studies. In contrast to the work by Steenbakkers et al [8], who employed a 10 mm margin inferiorly, we did not find a significant difference in predicted dose to the penile bulb. The dose to this structure was low in the current study for both MRI- and CT-defined target volumes, probably as a result of the 5 mm margins used, which excluded much of the penile bulb from the PTV. It is possible that a difference in dose to the penile bulb between MRI and CT plans may have become apparent with the use of larger margins inferiorly.

Like others [2, 6, 8, 9], we have found that, compared with CT, MRI delineation of the prostate results in treatment plans with a lower predicted dose to the rectum. We also found that the dose-sparing effect was confined to the lower rectum. A direct comparison with these studies is not possible, as different methods of expressing rectal dose were used.

If distortion-corrected MRI is to replace CT as the chosen modality for prostate radiotherapy planning, then account needs to be taken of the lack of electron density information from MRI. From our centre, Lee et al [11] have shown the feasibility of assigning bulk electron density data to pelvic MRI images for prostate radiotherapy planning. Using their technique, less than 2% difference in dose was found between MRI and CT in the high-dose regions of the plans. Chen et al [30] contend that no account needs to be taken of tissue heterogeneity for pelvic radiotherapy planning. In their study, in addition to planning CT, MRI images were acquired on a low-field open scanner and corrected for gradient distortion. Plans based on MRI and CT, using internal contours defined using MRI, were produced. The purpose of the study was to examine the effect of residual geometric distortion on the dosimetry of radiotherapy plans produced using MRI compared with CT.
and without using tissue heterogeneity correction. Less than 2% dose difference was seen between MRI- and CT-derived plans.

A criticism of the current study is that no measures were taken to achieve a consistent rectal volume for CT and MRI scans. This led to differences in the position of the anterior rectal wall and, consequently, the position of the prostate between MRI and CT within each patient. In our current clinical radiotherapy practice, we do not attempt to control rectal filling and did not seek to do so for the purpose of this study. Some studies have employed enemas prior to scanning [8, 9] and/or have performed both scans on the same day. In the study by Parker et al [5], the use of intra-prostatic fiducial markers to match the position of the prostate between scans would have minimized the effect of organ movement. Although apparent differences in the AP position of the prostate, resulting from changes in rectal filling as visualized on CT and MRI, could affect predictions of rectal dose, we found little systematic difference between imaging modalities, and on average the rectal wall lay 0.3 mm more anterior on MRI than on CT.

In the current study, we employed the same patient positioning for MRI as for CT, including a flat-topped couch, in order to achieve comparability between imaging modalities. In the study by Steenbakkers et al [8], a consistent difference in the position of the anterior rectal wall and posterior prostate was noted such that the MRI-defined anterior rectal wall at the level of the mid-prostate lay further ventrally (anteriorly) than on CT. This was attributed to differences in the shape of the scanning tabletop between imaging modalities and the use of supports behind the knees for CT but not for MRI.

A number of other points should be considered when interpreting the current study. Firstly, this is a planning study, and doses to OARs are predictions, although evidence exists to support the predictive value of DVH data for the rectum in terms of radiation sequelae [31–35]. Secondly, the clinical significance of the ~10% absolute reduction in the volume of the lower rectum/anal canal treated to doses of 45–65 Gy is uncertain.

Three patients in this study were excluded from analysis because of changes in the rectal diameter, and consequently prostate position between scans. This serves as a reminder of the phenomenon of inter-fraction movement. Dietary modification or laxatives are used in an attempt to achieve consistent rectal filling, but there is at present a lack of published evidence to support such measures routinely. Other measures include intra-prostatic fiducial markers [36–38], intrarectal devices [39] and image guidance using cone-beam CT [40]. If the potential benefits of improved target definition are to be realized, then consideration should be given to employing MRI with such techniques.

Conclusions

We have shown that it is feasible to use distortion-corrected $T_2$ weighted MRI with CT in this setting. The smaller prostate volume defined with MRI compared with CT is in keeping with previous studies using uncorrected MRI. We have demonstrated that this results in a reduction of the predicted radiotherapy dose to the rectum, in particular the anal canal. The clinical significance of this remains uncertain.

Acknowledgments

This work was undertaken in The Royal Marsden NHS Trust which received a proportion of its funding from the NHS Executive; the views expressed in this publication are those of the authors and not necessarily those of the NHS Executive. This work was supported by The Department of Health New and Emerging Applications of Technology (NEAT) program, grant number B132, the Institute of Cancer Research, the Bob Champion Cancer Trust and Cancer Research UK Section of Radiotherapy (CUK) grant number C46/A2131.

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