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CLINICAL INVESTIGATION **Rectum**

RECTAL MOTION IN PATIENTS RECEIVING PREOPERATIVE RADIOTHERAPY FOR CARCINOMA OF THE RECTUM

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Purpose: To assess the movement of rectum, mesorectum, and rectal primary during a course of preoperative chemoradiotherapy.
Methods and Materials: Seventeen patients with Stage II or III rectal cancer had a planning CT scan with rectal contrast before commencement of preoperative chemoradiation. The scan was repeated during Weeks 1, 3, and 5 of chemoradiation. The rectal primary (gross tumor volume), rectum, mesorectum, and bladder were contoured on all four scans. An in-house biomechanical model-based deformable image registration technique, Morfeus, was used to measure the three-dimensional spatial change in these structures after bony alignment. The required planning target volume margin for this spatial change, after bone alignment, was also calculated.
Results: Rectal contrast was found to introduce a systematic error in the position of all organs compared with the noncontrast state. The largest change in structures during radiotherapy was in the anterior and posterior directions for the mesorectum and rectum and in the superior and inferior directions for the gross tumor volume. The planning target volume margins required for internal movement for the mesorectum based on the three scans acquired during treatment are 4 mm right, 5 mm left, 7 mm anterior, and 6 mm posterior. For the rectum, values were 8 mm right, 8 mm left, 8 mm anterior, and 9 mm posterior. The greatest movement of the rectum occurred in the upper third.
Conclusions: Contrast is no longer used in CT simulation. Assuming bony alignment, a nonuniform margin of 8 mm anteriorly, 9 mm posteriorly, and 8 mm left and right is recommended.

Rectal motion, Preoperative chemoradiation, Planning target volume.

INTRODUCTION

There is extensive literature on the effect of normal rectum distension when treating prostate cancer (1–4). However, there is little information on the movement of the rectum when the malignancy is rectal (5). The important difference is that in prostate radiation, the rectum is a normal tissue for which the treatment volume should be minimized. In contrast, in the radiation of rectal cancer it is important to ensure that the planning target volume (PTV) includes the gross tumor volume (GTV) and the clinical target volume (CTV), which itself includes both the rectum and the mesorectum. Nuyttens *et al.* (6) have described the extent of motion of the CTV for conventional adjuvant therapy to the rectum, perirectal tissues, and regional lymph nodes, but not that of the organs themselves. More recently, Tournel *et al.* (7) described the intrafraction motion of the mesorectal space in 10 patients treated with tomotherapy who had megavoltage CT scanning before and after 10 fractions of radiotherapy. In a review of imaged-guided radiotherapy in rectal cancer, Ippolito *et al.* (5) commented that there had been no research into the movement of the mesorectum during treatment, and that such information is essential to ensure better treatment control. However, more recently Nijkamp *et al.* (8) reported on the deformation of the mesorectum and anus during hypofractionated radiotherapy. We endeavored to assess the extent of interfraction motion of the rectum, mesorectum, and GTV during a 5-week course of radiotherapy and to determine an appropriate PTV. In addition, the difference in

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motion of the upper, middle, and lower third of the rectum and the effect of changes in bladder volume were assessed.

METHODS AND MATERIALS

Patient data

After obtaining consent, 17 patients with clinical Stage II or III rectal cancer had a helical planning CT scan (GE Medical Systems, Highland Heights, OH) in the prone position (Scan 1) performed before the start of preoperative chemoradiation, and during Weeks 1 (Scan 2), 3 (Scan 3), and 5 (Scan 4) of treatment. All patients received 50 Gy in 2-Gy fractions over 5 weeks with concurrent 5-fluorouracil infusion. There was no specific bowel or bladder routine used for scanning or treatment. Before the planning CT scan, to help indentify the GTV, rectal contrast was inserted into the rectum; however, this contrast was not administered for the treatment scans, to better reflect treatment conditions and to avoid patient discomfort. Rectal contrast consisted of 20 mL of barium sulphate suspension and 10 mL of air (Fig. 1). After registration of the CT scans according to the pelvic bones, the GTV, rectum, mesorectum, and bladder were contoured by one observer (E.S.) on every 2-mm axial CT slice for the four scans and subsequently reviewed by a second observer (J.B.). Assessment of the GTV tended to be more uncertain in later scans compared with the pretreatment scan owing to lack of rectal contrast and also possible radiation effects on the tumor. The rectum was contoured cranially until the sigmoid flexure location (assessed as where the sigmoid started to curve away from the rectum in an anterosuperior direction).

Deformable registration

A deformable image registration technique based on finite element modeling in-house software, Morfeus (9–11), was used to measure the three-dimensional (3D) spatial change, in addition to positional change relative to the bony pelvis, in the rectum, GTV, and mesorectum. The contours generated for each organ were converted into tria-element meshes (constructed from three points), which describe the 3D surface of the organ. These tria meshes were then converted into full-volume tetrahedral (four-point) meshes. After alignment of the bony pelvis, the two organs from different scans were rigidly aligned according to their center of mass. A guided surface projection aligned the tria-elements on the primary organ to a surface generated from the secondary organ using a finite element modeling preprocessing package (HyperMesh v7.0; Altair Engineering, Troy, MI). The displacement of each element formed the boundary condition for the finite element analysis of the tetrahedral volume representation (ABAQUS; ABAQUS, Pawtucket, RI). The analysis determined the displacement of each node of the mesh according to given biomechanical material properties. Linear elastic material properties were assigned for each organ. The rectum, mesorectum, and bladder were assigned a Young's modulus of 10 kPa, and the GTV was assigned a Young's modulus of 7.8 kPa. All organs were considered incompressible with a Poisson's ratio of 0.499.

In the case of the rectum and mesorectum, it became apparent that there was potential misalignment in the superior–inferior (SI) direction, owing to contouring difference lengths of rectum. To correct for this potential misalignment the anorectal junction at levator ani muscle was aligned, and the cranial extent was cropped to the minimum length contoured on any scan, so that the length of the rectum and mesorectum was constant within each patient. The projection of the points on the surface of the primary representation of the organ onto the surface of the secondary representation was constrained to the axial direction. Consequently, motion can only be reported in the left–right (LR) and anterior–posterior (AP) directions for the rectum.

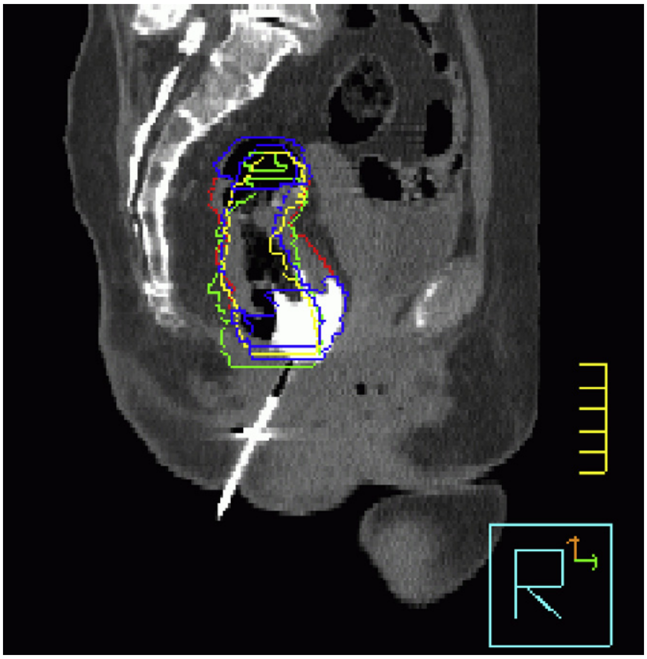

Fig. 1. Coronal view of rectal contours after fusion with bony alignment. The contour in red represents the rectal contour on the pretreatment planning CT scan with rectal contrast. The displacement of the anterior rectal wall in the prone position secondary to the contrast is clearly seen.

For each patient the mean motion was averaged over all elements in the finite element model in each direction, over each of the scans, and then over all patients. For the GTV, these quantities were computed for each scan as the mean displacement of all points in the volume and the standard deviation (SD) of the displacement of all points in the volume. The rectum and mesorectum were treated as hollow tubes, so these quantities were computed as the mean of all points on the surface and the SD of all points on the surface (Fig. 2).

Because contrast was used in the planning scan and not the on treatment scans, bias could be introduced by the contrast. In fact, observed deformation was largest in the pretreatment scan. To address this potential confounder, the analysis was performed using two methods: (*1*) including the planning scan and the systematic error introduced by the contrast, and (*2*) only including the noncontrast images obtained during treatment, to evaluate the random uncertainty over the course of treatment.

Calculation of PTV

To calculate the PTV expansion, the displacement of the mesh nodes closest to the edge of expansion was evaluated. For example, when determining the anterior expansion, the anterior-most 5% of the mesh nodes were used for quantification of the anterior displacement. In addition, the measured systematic uncertainty is larger than the true systematic uncertainty, owing to the limited number of scans per patient, and it includes some random uncertainty. The true systematic uncertainty can be estimated using this equation (12):

$$\sum_{measured} = \sqrt{\sum\nolimits_{true}^{2} + \left(\frac{s}{\sqrt{n}}\right)^{2}}, \tag{1}$$

where Σ_{measured} is the measured systematic uncertainty, Σ_{true} is the true systematic uncertainty, σ is the random uncertainty, and n is the number of fractions, where data are available.