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Rainbow IMRT and Volumetric Imaging for Anterior Mesenteric Targets

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Abstract

Mesenteric masses can considerably shift positions between fractions of radiation therapy (RT). With image-guided RT, we can adapt our treatment delivery daily to target the mass while avoiding surrounding structures. We report the case of a highly-mobile mesenteric mass which required adaptive planning from a traditional “butterfly” intensity modulated radiation therapy (IMRT) plan to an anterior “rainbow” beam arrangement to permit shifting of the isocenter without compromising target coverage or increasing dose to organs-at-risk.

Introduction

Mesenteric involvement of non-Hodgkin lymphoma (NHL) is common [1], and radiation therapy (RT) can improve outcomes for NHL patients [2]. However, mesenteric nodal masses are subject to mobility that can complicate accurate radiation delivery. We report a case of a highly mobile mesenteric mass that shifted position daily. It was treated with an IMRT plan using an anterior-weighted “rainbow” beam arrangement previously validated for mediastinal targets [3] to address this unpredictable inter-fractional target motion.

Teaching Case

A 34-year-old male presented with a 6.5×4.2×9.0 cm PET-avid mesenteric mass, biopsy positive for grade 1-2 follicular lymphoma, with suspected transformation to diffuse large B-

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Conflicts of interest:

No actual or potential conflicts of interest exist.

cell lymphoma based on Ki-67 of 70-80%, necrosis, and high standardized uptake value (SUV) of 16.2 (Figure 1A, 1B). He received 3 cycles of anthracycline-based chemotherapy, and follow-up PET-CT showed a complete metabolic response (SUV of 2.4, Five-point scale=2) with a 4cm residual mass (Figure 1C, 1D).

He was recommended consolidation RT (30 Gy, 15 fractions) using IMRT, involved-site radiotherapy (ISRT) [4], and daily CT-image guidance. Deep-inspiration breath hold (DIBH) was utilized to minimize respiratory-induced motion [5]. The clinical target volume (CTV) was created per the International Lymphoma Radiation Oncology Study Group (ILROG) ISRT guidelines with a 7mm margin for the planning target volume (PTV). The initial plan (Day 0) used an anterior-posterior weighted “butterfly” beam arrangement (Figure 2A) [6], and resulting target coverage was excellent ($D_{95} > 95\%$) with minimal normal structure dose (Figure 2B-2E).

We performed daily CT-based Image Guided Radiotherapy (IGRT) using a high-speed in-room CT scanner (GE Medical Systems) integrated with the Varian Exact Targeting System [7]. The CTV, OARs, and isodose lines were overlaid on the daily-acquired CT images for physician coverage evaluation and shifts before treatment. The typical time between CT image acquisition and completion of treatment was 20 minutes. During this time, the patient had to lie quietly in the treatment position in an effort to reduce intra-fractional target motion. Any fraction for which a shift greater than 1 cm is required, the treating physician reviewed the alignment and the required shifts.

Between the CT simulation scan (Day 0) and the first treatment (Day 1), the mesenteric mass moved significantly (4.5cm lateral, 2.2cm anterior-posterior, 2.2cm superior-inferior) (Figure 3A, 3B). Using only bony alignment, less than 11% of the PTV would have received 30 Gy (Figure 3C). The large shift required to encompass the mass in the treatment plan would have significantly increased dose to the left kidney (Figure 3D, 3E) (max dose from 10.9 Gy to 29.3 Gy; V_5 from 4% to 14%) and still resulted in suboptimal PTV coverage (D_{95} 89.5%) (Figure 3E). Therefore, re-planning was performed using the first daily CT-on-rails image set (Day 1 scan).

Given concerns for future mass migration, multiple other beam arrangements were explored. Based on previous experience with mediastinal targets [3], and taking into account the drastic movement between the simulation and first fraction, a new plan was designed with anterior IMRT beams in a “rainbow” arrangement (Figure 4A-4D) which permitted future isocenter shifts without dramatic increases in OAR dose or compromised target coverage. A planning organ at risk volume (PRV) structure was created as a 1.2cm expansion of the left kidney and used in the planning process (Figure 4A, denoted with arrow). This “rainbow” plan resulted in excellent coverage of the PTV, with D_{95} of 30Gy. D_{max} to the right kidney was 7.1 Gy and left kidney was 4.7 Gy (Figure 4E).

On the second fraction (Day 2), another significant shift was required from the CTV Day 1 position (Figure 5A, in yellow) to the CTV day 2 position (Figure 5A, in red colorwash). Using the new “rainbow” beam configuration, the shift did not result in increased kidney dose or decreased target coverage (Figure 5B). In fact, D_{max} to both kidneys decreased (3.5

Gy, left; 4.8 Gy, right). In addition, D₉₅ for the PTV was still 100%, whereas without this shift the D₉₅ for the PTV would have been only 41% of the prescription dose (Figure 5B). The mass displayed significant mobility in the lateral and superior/inferior directions from the time of simulation (Day 0, green) and throughout therapy (Day 1, yellow; Day 2, red) as seen in the axial (Figure 5C), coronal (Figure 5D) and sagittal (Figure 5E) planes. The patient continued to require shifts throughout the rest of treatment, with a maximum shift of 5.27cm lateral, 3.53cm anterior-posterior, and 0.96cm superior-inferior. The large applied shifts were applied to the treatment planning scan and evaluated dosimetrically to assure satisfactory target coverage and limited OAR dose. Ultimately, re-planning was not required.

The patient tolerated treatment well with minimal side effects and is disease-free at 2 months post-treatment.

Discussion:

Advances in technology such as IMRT and image-guidance have allowed radiation oncologists to treat smaller fields with increased accuracy. Historically, mesenteric NHL was treated with three-dimensional (3D) radiation to the entire abdomen, which guaranteed treatment of the target [8]; however, these large fields resulted in undesirable acute side-effects (e.g., nausea, diarrhea) and limited prescription dose due to normal tissues tolerances (e.g. liver, kidneys) [8, 9]. The use of smaller ISRT fields [4] and more conformal IMRT plans allow for reduced toxicity [10], though technology must be incorporated to ensure correct treatment. Daily volumetric imaging is required to 1) guarantee accurate treatment delivery to the target and 2) provide awareness of dose to normal structures during isocenter shifts.

Mesenteric masses move independently of bony anatomy and alignment to the skeleton alone can result in significant under-dosing of the target. Therefore, this type of treatment requires daily CT image guidance to localize the target and ensure accurate tumor coverage [7, 11]. On the other hand, when CT imaging reveals the need for large shifts (>1.5 cm), doses to OARs can increase dramatically. This is especially concerning when using higher doses (>45 Gy) as spinal cord and kidney tolerance may be exceeded.

The “rainbow” beam arrangement allowed us greater flexibility to shift the isocenter for target coverage and still spare critical structures. This beam arrangement is best able to create homogeneous treatment plans for anteriorly-located lesions with concurrent sparing of more posterior critical structures. This beam arrangement is best suited for anteriorly located lesions that have limited posterior placement, as occurred in this case.

While many are hesitant to deliver radiotherapy to mobile locations such as mesenteric lymph nodes, our previous work showed that mesenteric involvement of NHL can be successfully targeted with RT [12]. At our institution, we have access to diagnostic-quality CT imaging with our CT on rails unit. Many centers have cone-beam CT imaging for soft tissue target verification. It is known that cone-beam CT has inferior image quality; however, imaging features can be improved using adjustments to acquisition parameters. Utilization of cone-beam CT imaging is typically more challenging for patients with large body habitus,

and we recommend that practitioners confirm that the target can be easily and accurately visualized on CBCT before committing to treatment.[13]

It is important to also consider intra-fractional or post-treatment imaging to confirm the target's position, given that mesenteric targets could change position even during the treatment delivery due to peristalsis, abdominal organ motion, etc. Lischalk et al showed that significant inter- and intra-fractional discrepancies in the location of gastrointestinal targets can occur when using 4D-CT.[14] They suggest that motion suppressing methods (such as deep inspiration breath hold) could mitigate realtime tumor motion, especially during treatments with long fraction times. We routinely utilize DIBH for our mesenteric cases in an attempt to minimize possible intra-fractional motion. Although we did utilize DIBH, we did not confirm the absence of intra-fraction motion radiographically. For those considering this approach, implementation of intra- or post-treatment imaging to confirm target position is recommended. We also made efforts to limit the time between scan acquisition and treatment delivery in order to limit intra-fractional variation. This case report provides an extreme example of mesenteric motion and shows that safe and effective treatment can be accomplished using a rainbow beam arrangement IMRT plan, localized ISRT fields, and daily CT-image guidance. In facilities with the appropriate technologic capabilities, RT should be considered for the treatment of mobile abdominal masses.

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Figure 1: Diagnostic Pre- and Post-Chemotherapy Imaging Studies.

Baseline PET scan at diagnosis (A), CT at diagnosis (B), post-chemotherapy PET scan (C) and CT scan (D) showing residual mass (arrow)

Figure 2. Original IMRT Radiation Plan with “Butterfly” Beam Arrangement

A. Axial image from initial butterfly IMRT beam arrangement (Day 0) with three anterior (0° , 25° and 335°) and two posterior (165° and 195°) beams targeting the CTV (day 0, red) and PTV (day 0, teal). Dose distribution in the axial (B), coronal (C), and sagittal (D) dimensions. The 5 Gy isodose line spares the kidneys. The dose volume histogram (DVH) illustrating excellent target coverage with a favorable OAR dose profile (E).

Figure 3. IMRT Butterfly Plan adaptation after target movement on day one.

A. Axial image from CT-on-rails scan from the first treatment day with isodose lines placed according to the original plan isocenter. The mesenteric mass moved over 4 cm on the first day (CTV_{day1} depicted in red and PTV_{day1} depicted in blue). B. Axial image of original mass location (CTV_{day0} in yellow and PTV_{day0} in green) and new location on the first treatment day (CTV_{day1} in red and PTV_{day1} in teal). C. DVH of the original butterfly plan based on original isocenter location illustrating poor coverage of the CTV and PTV based on the actual location of the mass (CTV_{day1} and PTV_{day1}). D. IMRT butterfly plan applied to shifted Day1 target (CTV_{day1} and PTV_{day1}) based on daily CT-on-rails imaging. The Day0 location of the target is also visualized (CTV_{day0} in yellow, PTV_{day0} in green). E. The DVH based on CT-on-rails shift to the new target location (CTV_{day1} and PTV_{day1}) results in increased left kidney dose and suboptimal PTV coverage.

Figure 4. New Rainbow IMRT planning performed after large target shifts.

A. Axial image from initial rainbow IMRT plan with anterior beam arrangement (25°, 65°, 100°, 295°, 320°, 335°) targeting the CTV_{day1} (red) and PTV_{day1} (teal). A 1.2 cm kidney margin was used as an avoidance structure (arrow). Dose distribution in the axial (B), coronal (C) and sagittal (D) dimensions. The IMRT rainbow plan DVH (E) demonstrated excellent target coverage and low OAR dose.

Figure 5. Rainbow IMRT utilized successfully throughout treatment with continued mass motion

A. Axial image from CT-on-rails plan with isodose lines in the actual location of the mass on day 2 of treatment. CTV_{day2} (red), PTV_{day2} (teal), CTV_{day1} (yellow), PTV_{day1} (green) with DVH based on the fitted position after shift showing excellent coverage of day2 volumes (B). Images depicting location of targets from day 0 (green), day 1 (yellow) and day 2 (red) in axial (C) coronal (D) and sagittal (E) planes.