Advances in Radiation Oncology (2022) 7, 100933

advances in radiation oncology

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Teaching Case

Substantial Distortion of the Aorta During Celiac Plexus Stereotactic Body Radiation: A Case Report

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Received January 4, 2022; accepted February 18, 2022

Introduction

Celiac plexus pain, generally, but not exclusively, caused by pancreatic cancer compression or invasion,[1] is characterized by low back pain that can radiate anteriorly in a belt-like distribution. This pain is difficult to control with opioids and nerve blocks, and so stereotactic body radiation (SBRT) has been proposed as a palliative treatment to interrupt neurotransmission and reduce pain. A single-arm multicenter phase 2 trial (NCT03323489) is exploring its analgesic benefit in cancer patients with severe celiac plexus pain.[2]

Because abdominal organ motion is influenced by both respiration and changes in luminal gastrointestinal organ position and filling, SBRT to abdominal structures requires careful motion management.[3] Approaches include avoiding gassy foods and treating on an empty stomach, as well as one or a combination of breath hold, respiratory gating, abdominal compression, real-time tumor tracking, or motion-encompassing planning with four-dimensional computed tomography (4DCT). The chosen approach is combined with soft tissue image guidance at the time of treatment, most often using cone beam CT (CBCT). Although the location of the celiac plexus varies, it is embedded in the fat overlying the anterolateral surface of the aorta for several centimeters within an area bounded by the top of the twelfth thoracic vertebra (T12) and the bottom of the second lumbar vertebra (L2).[4] The plexus is generally not visible on CT, and so the aorta is used not only as the surrogate for the location of the celiac plexus, but also as the structure to which the soft tissue match is performed at the time of SBRT; its position, in the experience of the trialists, is reliably replicated between simulation and treatment. However, the aorta of the patient described herein showed substantial distortion along its length, rendering a challenging treatment setup for SBRT treatment.

Case

A 75-year-old woman presented with *de novo* metastatic adenocarcinoma of the pancreatic head. The primary cancer directly invaded the celiac axis, and there were numerous liver metastases. Common bile duct compression by the tumor required a stent. Her past medical history included neurofibromatosis type 1 (NF-1), scoliosis, large bowel volvulus requiring resection at age 25 years, and small bowel resection for a benign tumor at age 50 years.

She had mid-back pain radiating up her spine and to her umbilicus, of an intensity ranging from 8 to 10 on a 10-point pain scale, poorly controlled on opioids. She

Sources of support: This work had no specific funding.
Disclosures: none.
Research data are stored in an institutional repository and will be shared upon request to the corresponding author.
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https://doi.org/10.1016/j.adro.2022.100933

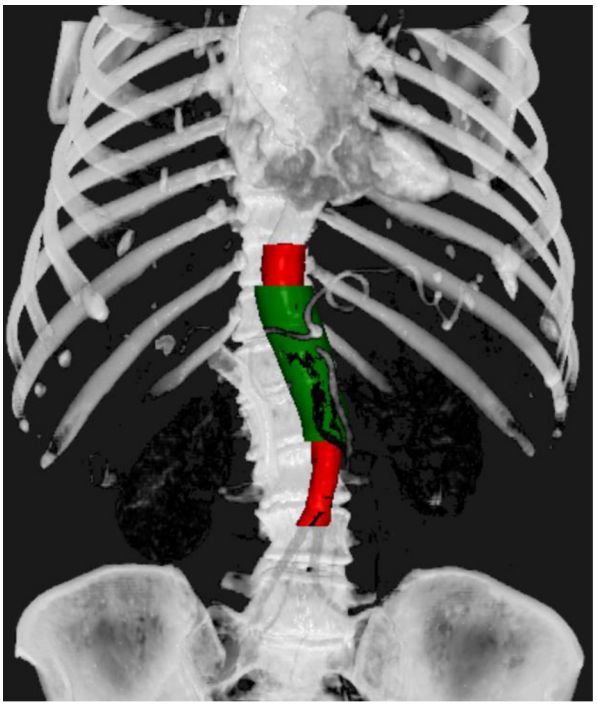

Fig. 1 Relative locations of the celiac plexus (green), aorta (red), and spine in this patient.

elected to participate in the clinical trial of single-fraction celiac plexus SBRT for palliation of the pain, wherein 25 Gy in one fraction is delivered to a 5-mm expansion of the anterolateral aorta from T12 to L2 (Fig 1).

Free-breathing helical and 4DCT image sets were obtained, the former for radiation treatment planning and the latter for motion characterization. The high-dose regions targeting the celiac plexus are termed planning target volumes (PTV) in the NCT03323489 protocol. A 5-mm expansion of the anterolateral aorta from the top of T12 to the bottom of L2 delineates the celiac plexus and was targeted by the PTV 25 Gy. The PTV 20 Gy was a 5-mm expansion of this. The dose to the area of PTV 25 Gy or 20 Gy within 10 mm of, but more than 5 mm from, the bowel was decreased to 15 Gy, and the dose to the area within 5 mm of bowel was decreased to 10 Gy (Fig 2). As is permissible in the trial protocol, a 10 mm expansion of the primary tumor was treated as part of the same plan to 10 Gy in one fraction (Fig 3). The dose-volume metrics are detailed in Table 1.

At treatment, a CBCT was obtained, and the vertebral bodies were used for initial image registration. A soft tissue match to the aorta was then done, wherein the contours of the celiac plexus and aorta were overlaid from the planning CT on the CBCT, and all dose-limiting organs at risk (OARs) were assessed. The first CBCT showed a good match at the central celiac plexus target volume, but there was substantial bending and deviation of the aorta superiorly and inferiorly, in opposite directions (Fig 4a). There was an attempt to manually shift the patient to

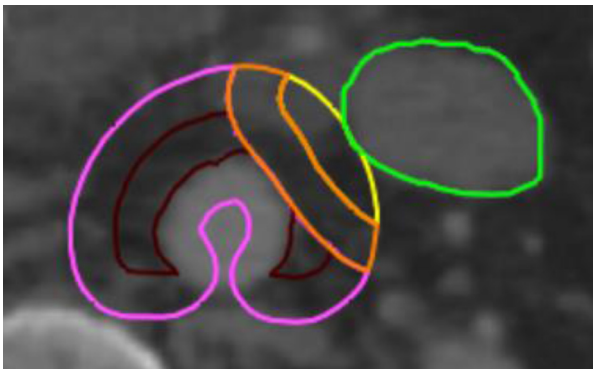

Fig. 2 Celiac plexus planning target volumes (PTV) dose painting. PTV 25Gy (maroon); PTV 20Gy (pink); PTV 15Gy (orange); PTV 10Gy (yellow); duodenum (green).

account for this, and the second CBCT showed an improved but still imperfect match, with part of the assumed celiac plexus still outside of the PTV 25 Gy (Fig 4b). The patient was again manually shifted, and the position visualized on the third CBCT, which had the best alignment of the high-dose regions and sparing of OARs (Table 1), was used for treatment (Fig 4c). Despite residual anatomic change, the estimated doses to OARs were within prespecified limits (Table 1).

Table 2 confirms that the position of the celiac plexus on third CBCT was closest to its position on simulation CT, with the dice similarity coefficient and the maximum and mean distance-to-agreement between the third CBCT and the simulation CT superior to those of CBCT 1 and 2.

Within 24 hours of SBRT treatment, the patient reported that her pain had decreased to 2 to 3 on a 10-point pain scale. Her 24-hour oral morphine equivalent dose on the day of treatment was 62.5 mg; the next day, it had decreased to 42 mg. At 1, 2, 5, and 6 weeks post-SBRT, she had no reported toxicities.

Discussion

This is the first report of substantial, multidirectional aorta displacement relative to the spine from simulation to on-treatment scans in the supine position, and the first instance of misalignment of the aorta relative to the vertebral bodies that has been seen on the celiac plexus SBRT trial. Surgical reports have described significant aorta shifts between prone and supine positions, with the aorta lying posterolateral to the thoracolumbar spine in the supine position and moving to a more anteromedial position when prone.[5–7] Its mobility is more pronounced at midthoracic spinal levels, but significant changes in aorto-vertebral angle[5] and distance[6] have been shown as inferior as T12. At L1 and L2, Huitema *et al.* found that the angle change was not significant between supine and prone positions.[5] This case, however, provides evidence

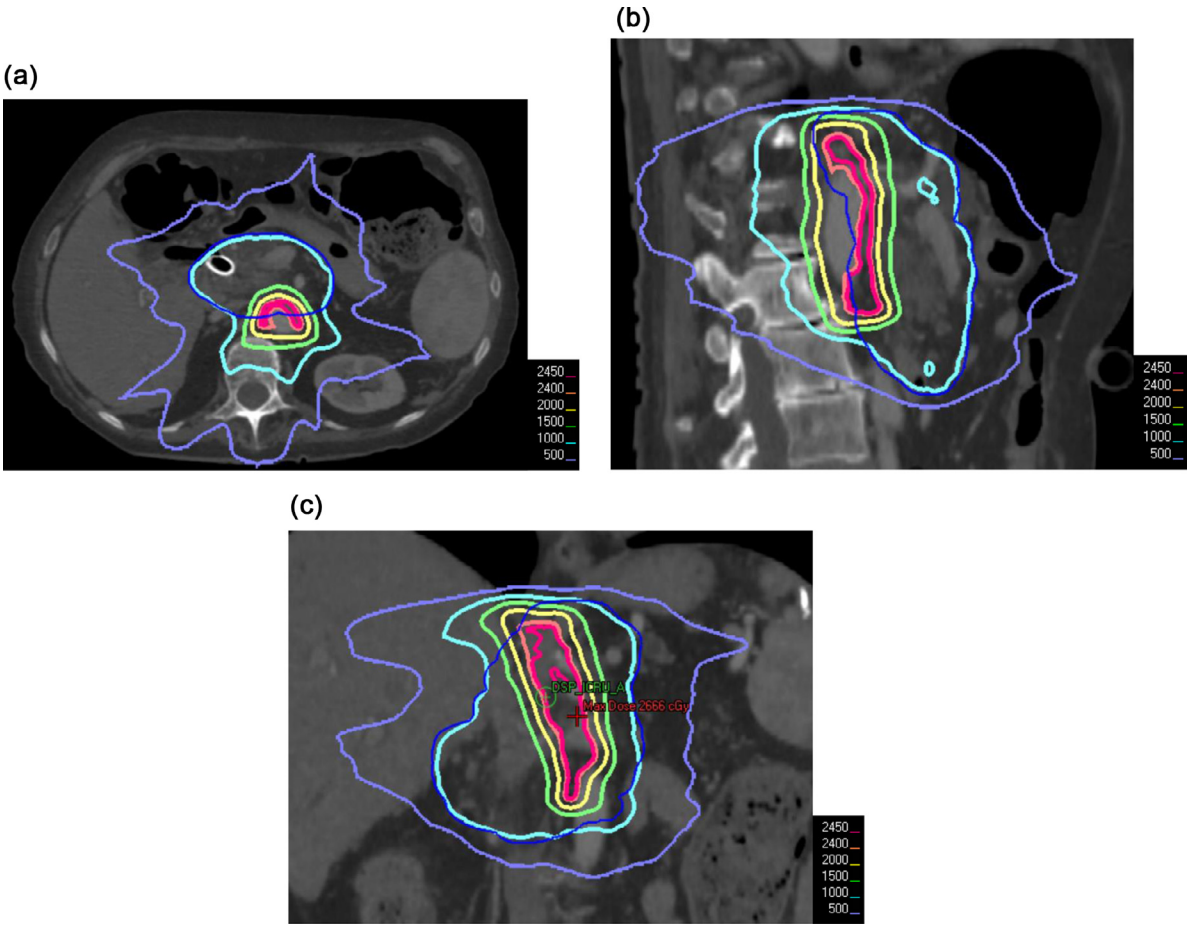

Fig. 3 Radiation plan. Dark blue line represents the tumor planning target volumes of 10Gy. The isodose lines correspond to the dose level scale: 24.5 Gy (pink), 24 Gy (orange), 20 Gy (yellow), 15 Gy (green), 10 Gy (light blue), 5 Gy (purple). (a) Axial view. (b) Sagittal view. (c) Coronal view.

for the possibility of aorta displacement relative to the lumbar spinal column in the supine position. SBRT relies on consistent positioning of targets from the time of simulation to treatment to ensure the high prescription dose is delivered to the target and the OARs are spared; celiac plexus SBRT additionally relies on aorta-spinal column alignment to ensure that the aorta is a reproducible surrogate for the celiac plexus.

Table 1 Dose-volume metrics for key organs at risk

Organ at risk	Evaluation criteria	Plan metric
GI luminal tract	V11Gy <1 cm^3	0.37 cm^3
GI luminal tract	V12Gy <5 cm^3	0.01 cm^3
GI luminal tract	Dmax <1500 cGy	1215 cGy
Bowel bag	Dmax <1500 cGy	1493 cGy
Large bowel	V11Gy <1 cm^3	0 cm^3
Large bowel	V12Gy <5 cm^3	0 cm^3
Large bowel	Dmax <1500 cGy	1050 cGy
Stomach-duodenum	V11Gy <1 cm^3	0.33 cm^3
Stomach-duodenum	V12Gy <5 cm^3	0.01 cm^3
Stomach-duodenum	Dmax <1500 cGy	1215 cGy
Spinal canal	Dmax <1000 cGy	952 cGy

Abbreviatons: GI = gastrointestinal.

The patient's medical history may have contributed to the aorta motion relative to the vertebral bodies: connective tissue dysplasia may be a manifestation of (NF-1),[8] and her diagnosis may have caused ligament laxity resulting in an aorta with a looser connection to surrounding structures, leading to the displacement of the aorta seen relative to the vertebral bodies from simulation to the time of treatment.

SBRT requires reproducible patient setup and meticulous image guidance; this is especially important for single-fraction SBRT, like in the 25 Gy SBRT celiac plexus clinical trial. A mismatch can result in a partial miss or substantial underdosing, with overdosing of critical OARs and a resultant risk of toxicity that may become excessive and life-threatening. The addition of a planning OAR can account for internal organ motion and setup error.

In the palliative setting, the risk-benefit analysis of a given treatment prioritizes short- and medium-term benefits, with less weight given to long-term risks but with

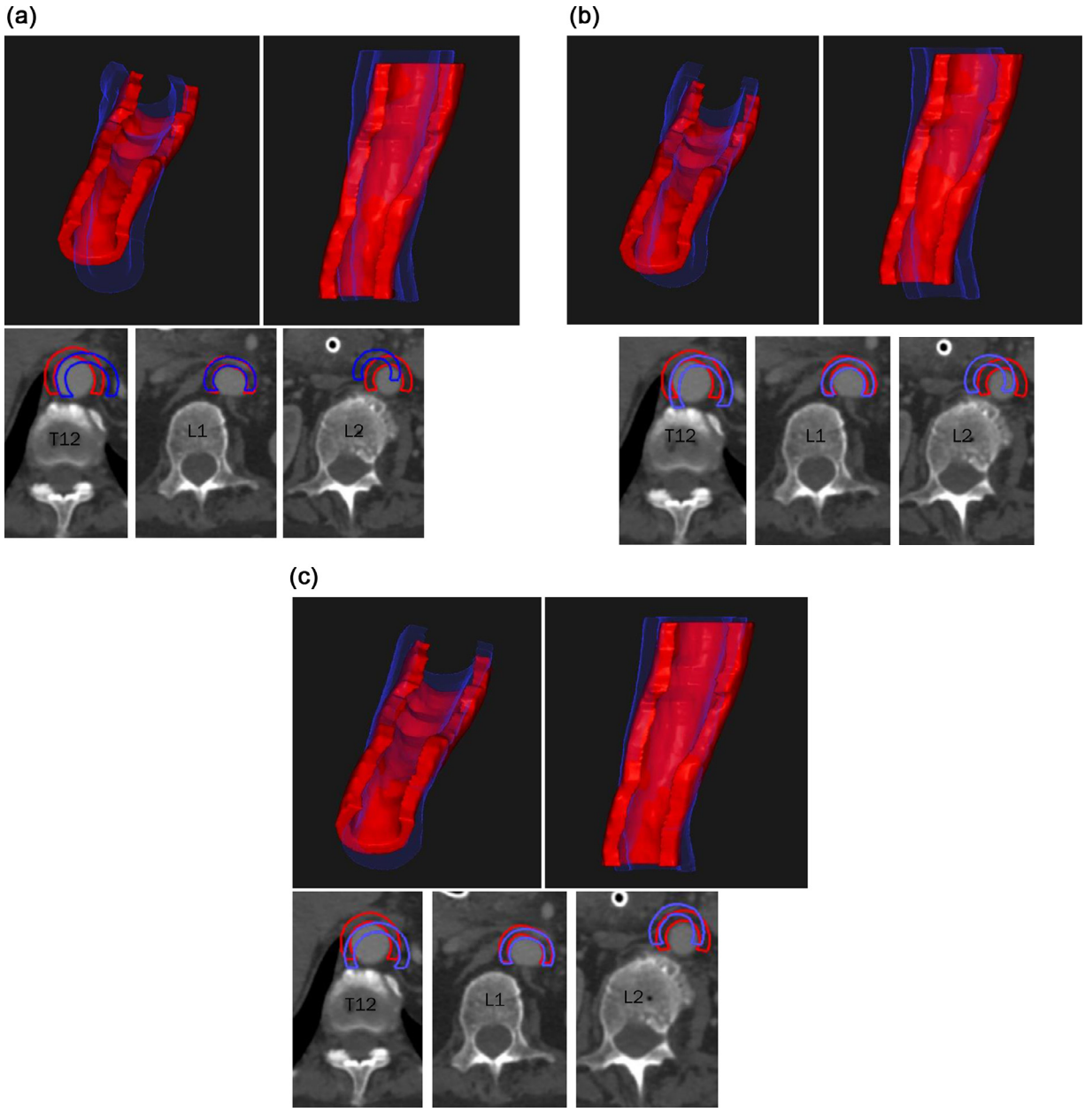

Fig. 4 Celiac plexus position on cone beam computed tomography (CBCT) (blue) and simulation (red). (a) CBCT 1. (b) CBCT 2. (c) Final CBCT, used for treatment.

Table 2 Contour similarity metrics between high-dose regions on each CBCT and the simulation CT

	Dice coefficient	Maximum distance-to-agreement (mm)	Mean distance-to-agreement (mm)
CBCT 1	0.474	12.6	2.27
CBCT 2	0.445	8.56	2.14
CBCT final	0.53	7.59	1.55

Dice similarity coefficient ranges from 0 (no agreement) to 1 (perfect agreement).
Abbreviations: CBCT = cone beam computed tomography.

avoidance of acute injury remaining imperative. CBCT assessment includes a hierarchical evaluation of target coverage and OAR dose; for celiac plexus SBRT, coverage of the celiac plexus adjacent to the tumor is the highest priority, followed by coverage of the full celiac axis, and then avoidance of gastrointestinal OARs. In this case, the first and second CBCTs did not meet these goals, and so the patient was repositioned. The chosen treatment position of the high-dose PTV was not perfectly aligned with the simulation position due to the twisting nature of the aorta, but the dose to the celiac plexus, including the gross tumor invasion therein, was estimated to be covered by the 20-Gy PTV, and the dose to luminal structures, the motion of which is accounted for in the "bowel bag" contour, was estimated to be safe. The applied radiation therapy resulted in a rapid pain relief, reduction in analgesic requirements, and no toxicity within 6 weeks.

Bowel preparation before treatment is an additional technique that can improve matching, including when artifact obstructs identification of luminal structures, although this can be challenging for ill patients. In the future, online adaptive radiation may prove beneficial in improving the safety of single-fraction SBRT.

Conclusions

Here we present a case of multidirectional motion of the aorta relative to the thoracolumbar spine in the supine position that illustrates the importance of considering the mobility of the aorta in spine and celiac plexus SBRT.

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