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Carbon ion therapy

Comparison of carbon-ion passive and scanning irradiation for pancreatic cancer

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ABSTRACT

Purpose: To compare carbon-ion beam dose distribution between passive and scanning radiation therapies for locally advanced pancreatic cancer.
Materials and methods: Thirteen pancreatic cancer patients were included in this study. Four types of treatment planning with respiratory gating were calculated for each patient: a four-field box with passive irradiation (Plan 1), scanning irradiation (Plan 2), a three-field (150°, 180° and 210°) protocol with passive irradiation (Plan 3), and scanning irradiation (Plan 4). The irradiation plans each delivered 55.2 Gy (RBE) to the planning target volume (PTV) and were compared with respect to doses to the PTV and organs at risk (OARs).
Results: Plan 3 exceeded the dose assessment metrics to the spinal cord. Scanning irradiation plans (Plan 2 and, particularly, Plan 4) offered significantly reduced dosage to the stomach and the duodenum compared with passive irradiation.
Conclusion: Three-field oblique scanning irradiation for pancreatic cancer has the potential to reduce gastrointestinal exposure and influence of peristalsis on dose distribution.

Pancreatic cancer accounted for an estimated 46,420 cancer cases and 39,590 cancer deaths worldwide in 2014 [1]. Selected patients may be curable when treated with high-dose chemoradiotherapy, but delivery of high-dose radiation is limited owing to the proximity of organs at risk (OARs). Several dosimetric studies have reported that proton therapy improves the dose–volume histograms (DVHs) over conventional photon therapy and intensity-modulated radiation therapy (IMRT) by reducing excessive doses to normal tissues [2,3]. Carbon-ion beams provide a sharp lateral penumbra and narrow Bragg peak compared to proton beams [4], and demonstrate increased relative biological effectiveness (RBE).

Our carbon-ion beam therapy center was constructed in 1994, and has provided treatment to more than 9000 cancer patients [5]. Since, a constant spread-out Bragg peak (SOBP) over the beam field in a passive irradiation system can cause undesirable doses to normal tissues at the beam entry side of the target, dose escalation can be limited by the risk of gastrointestinal side effects. The scanning delivery system was developed to avoid these issues. Our facility began providing scanning irradiation without respiratory gating in 2011, with good clinical results [6].

We have clinical experience with four-field box treatments for pancreatic cancer using passive irradiation. Before starting pancreatic scanning irradiation, it is necessary to evaluate dose distributions between passive and scanning irradiation techniques. Here, we compared dose distributions among irradiation techniques using treatment planning software.

Materials and methods

Between November 2013 and February 2014, 13 patients were randomly selected from among patients with inoperable pancreatic cancer who underwent four-field box passive irradiation at our hospital. The characteristics of the enrolled patients are listed in Table 1. The patients were positioned in customized cradles (Moldcare®, Alcare, Tokyo, Japan) and immobilized with a low-temperature thermoplastic shell (Shellfitter®, Kuraray, Osaka, Japan). Treatment planning CT was acquired in four-dimensional (4D) mode under free breathing conditions (Aquilion One Vision Edition®, Toshiba Medical Systems, Otawara, Japan). The study was approved by the institutional review boards of our institutions and participating patients gave informed consent.

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Table 1
Patient characteristics. UICC stage grouping: Stage IIA: T3, N0, M0; Stage III: T4, Any N, M0; Stage IV: Any T, Any N, M1.

Characteristics	
Number of patients	13
Age, years	
Median (range)	63 (35–80)
Gender	
Male	8
Female	5
PS	
0	12
1	1
Stage (UICC 7th)	
IIA	2
III	8
IV	3
Tumor location	
Head	6
Body/tail	7
GTV size, cc	
Median (range)	13.9 (1.7–47.4)
CA19-9, U/ml	
Median (range)	684.5 (0.1–6560)

Treatment planning

Tumor extent was evaluated by CT, magnetic resonance imaging (MRI), and positron emission tomography (PET). A radiation oncologist manually delineated the gross tumor volume (GTV) and OARs on the CT images at peak exhale. Clinical target volume (CTV) was defined as the GTV plus a 5 mm margin plus locoregional lymph nodes and neural plexus regions. Planning target volume (PTV) was defined as the CTV with an added margin of at least 5 mm in all directions, modified if OARs were close to the GTV. The gating window was generally defined as a 30% duty cycle around the exhale phase. The mean (±standard deviation) GTV displacement at 30% of exhalation for all patients was 2.5 mm (±1.6 mm) in the anterior–posterior direction, 2.1 mm (±1.0 mm) in the lateral direction, and 2.5 mm (±1.6 mm) in the superior–inferior direction. The internal target volume (ITV) was calculated by adding the internal margin derived from 4DCT to the CTV.

Four respiratory-gated treatment plans were generated: a four-field box with passive irradiation (Plan 1) (our present standard technique), four-field scanning irradiation (Plan 2), a three-field (150°, 180°, and 210°) protocol with passive irradiation (Plan 3), and three-field scanning irradiation (Plan 4). The Plan 1 and Plan 2 treatment fraction schemes used three fractions at 0°, two fractions at 90°, four fractions at 180°, and three fractions at 270°. The Plan 3 and Plan 4 scheme used four fractions each at 150°, 180° and 210°. The carbon-ion dose for each plan totaled 55.2 Gy (RBE) in 12 fractions [7]. A patient collimator to reduce blurring of lateral dose distribution was manufactured for each field in passive irradiation, but is not required in scanning irradiation.

Doses were evaluated with regard to dose delivered to 95% of PTV (PTV-D95), dose to the most exposed 2 cc (D2cc) and volume receiving > n Gy (RBE) (Vn Gy (RBE)) of the stomach, duodenum

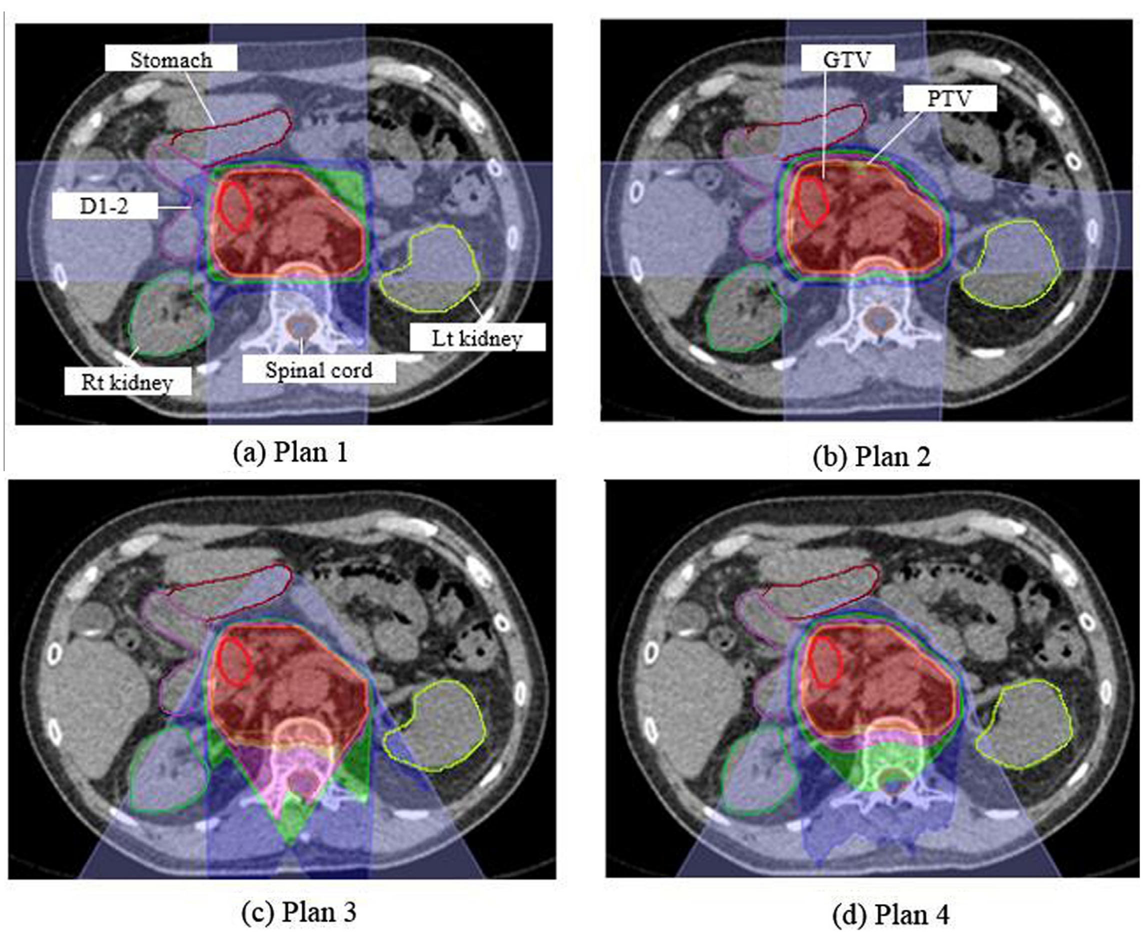

Fig. 1. Carbon-ion dose distributions in axial (patient no. 10) for (a) Plan 1, (b) Plan 2, (c) Plan 3 and (d) Plan 4. Red and yellow lines show gross tumor volume (GTV) and planning target volume (PTV), respectively. Red, yellow, pink, green, dark blue, and light blue isodose lines show 95%, 90%, 70%, 50%, 30%, and 10% of the prescribed dose, respectively. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)