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Effect of patient positioning on carbon-ion therapy planned dose distribution to pancreatic tumors and organs at risk

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ABSTRACT

Purpose: Pancreatic tumor treatment dose distribution variations associated with supine and prone patient positioning were evaluated.
Methods: A total of 33 patients with pancreatic tumors who underwent CT in the supine and prone positions were analyzed retrospectively. Gross tumor volume (GTV), planning target volume (PTV), and organs at risk (OARs) (duodenum and stomach) were contoured. The prescribed dose of 55.2 Gy (RBE) was planned from four beam angles (0°, 90°, 180°, and 270°). Patient collimator and compensating boli were designed for each field. Dose distributions were calculated for each field in the supine and prone positions. To improve dose distribution, patient positioning was selected from supine or prone for each beam field.
Results: Compared with conventional beam angle and patient positioning, D2cc of 1st-2nd portion of duodenum (D1-D2), 3rd-4th portion of duodenum (D3-D4), and stomach could be reduced to a maximum of 6.4 Gy (RBE), 3.5 Gy (RBE), and 4.5 Gy (RBE) by selection of patient positioning. V10 of D1-D2, D3-D4, and stomach could be reduced to a maximum of 7.2 cc, 11.3 cc, and 11.5 cc, respectively. D95 of GTV and PTV were improved to a maximum of 6.9% and 3.7% of the prescribed dose, respectively.
Conclusions: Optimization of patient positioning for each beam angle in treatment planning has the potential to reduce OARs dose maintaining tumor dose in pancreatic treatment.

1. Introduction

Pancreatic cancer has a high mortality rate [1]. Chemotherapy or chemoradiotherapy is the standard treatment option for locally advanced unresectable pancreatic cancer, with a median survival of approximately 10 months [2]. Higher radiation doses may improve tumor control, but are often limited by the radiosensitivity of the surrounding organs at risk (OARs). Morganti et al. performed a dose escalation study with external photon beam irradiation in unresectable tumors [3]. The prescribed doses were 39.6 Gy, 50.4 Gy, and 59.4 Gy in 1.8 Gy fractions. They reported that late toxicity was found only in the 59.4 Gy irradiated group (duodenal stenosis or duodenal ulcer). Because the radiation sensitivity and close anatomical relationships of surrounding OARs severely limits target volume margins, dose escalation studies always need to find a middle ground between sufficient dose for the tumor and the protection of OARs, particularly in the treatment of pancreatic tumors [4–6]. To avoid adverse reactions, dose reduction to OARs sometimes assumes priority over dose irradiation to the tumor in pancreatic treatment.

Compared to photon beam therapy, particle beam therapy allows better dose concentration to the target lesion [7]. Most proton therapy centers use a rotating gantry to deliver the prescribed dose to the tumor over multiple angles of irradiation [8,9]. However, carbon-ion facilities are constrained by the cost and difficulty of manufacturing and maintaining the much heavier rotating gantry [10]. When using fixed irradiation angles, treatment planning requires multiple computed tomography (CT) datasets with different patient positions to irradiate from multiple beam angles. In our center, using two fixed-beam ports, two CT datasets are acquired, one with supine and one with prone positioning to irradiate from four beam angles (0°, 90°, 180°, and 270°, International Electrotechnical Commission (IEC) gantry angle convention [11]) for pancreatic tumor treatment [12]. Irradiation from the anterior (0°), and the patient's left (90°) and right (270°) sides is planned using supine CT images, and that from the posterior (180°) is planned using prone CT images. The location of organs changes between the two positions. Since the patient couch can rotate perpendicularly to the patient's long axis (yaw), we can choose patient

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positioning from supine or prone in the horizontal beam field (90° and 180°). A rotating gantry using superconducting magnets is now being developed in our facility [13,14]. This will offer much greater flexibility in beam directions with optimal patient positioning. If we include the selection of patient positioning in treatment planning, better dose distribution can be arranged for each treatment.

In this study, we evaluated dose differences caused by patient positioning in the planning of carbon-ion treatment for pancreatic tumors.

2. Materials and methods

2.1. Patient selection and image acquisition

We retrospectively analyzed 33 pancreatic tumor patients who had undergone passive scattering carbon-ion treatment from 2013 to 2015 in our hospital. The tumors were located in the pancreatic head in 15 patients, in the body in 15 patients, and in the tail in 3 patients. There were 17 men and 16 women with a mean age of 68.0 ± 12.3 years (range: 36–90 years). All patients underwent respiratory gated CT scans using a 16-slice CT scanner (Light Speed® 16-slice; GE Healthcare, Waukesha WI, USA) under free breathing. Patients were immobilized on the treatment couch with a thermoplastic immobilization device (Shellfitter®, Kuraray Co., Ltd, Osaka, Japan). Patient respiration was monitored using a light emitting diode on the patient's abdomen and a position-sensitive detector. CT scans were performed supine and prone with 120 kV tube voltage, 300–380 mA tube current, 0.5 s per rotation, and 2.5 mm slice thickness.

2.2. Treatment planning

Radiation oncologists manually contoured the gross tumor volume (GTV), clinical target volume (CTV) (including the GTV, any lesions involving the neural plexus [the celiac and superior mesenteric region] or regional lymph nodes), and OARs (duodenum [D1-D2: 1st-2nd portion; D3-D4: 3rd-4th portion] and stomach) for both positions. A 2–3 mm was added to the CTV as a setup or interfractional margin and termed the planning target volume (PTV). The pancreatic treatment protocol in our hospital modified the PTV to spare excessive doses to OARs but aims to prevent dose degradation to high-risk CTVs on a patient-by-patient basis. Use of the different PTV definitions between supine and prone might be unfair to evaluate the dose differences related to positional changes of organs. Radiation oncologists, therefore, checked and modified all prone PTVs under the same strategy as supine for this study. Target volumes are summarized in Table 1. Dose distribution was calculated with our usual treatment planning system, (XiO-N®, Mitsubishi Electric Corporation, Tokyo, Japan). Optimum patient collimator and compensating boli were designed for each beam field and each patient position. Four different beam fields were used (0°, 90°, 180° and 270° in three, two, four, and three fractions, respectively) to administer the prescribed dose of 55.2 Gy (RBE) to the PTV for supine and prone, respectively. Dose was expressed as relative biological effectiveness (RBE) weighted dose (Gy [RBE]), which was defined as the absorbed dose of carbon ions multiplied by RBE [15]. Beam energy range was 290–400 MeV. Dose distribution differences were compared between the supine and prone positions for each beam field. As per our conventional planning, the beam field angle from anterior (0°), the patient's left side (90°), and right side (270°) was planned using the supine position, and that from the posterior (180°) was planned using the prone position.

2.3. Dose assessment

Dose assessments included D95 (lowest dose received by 95% of the target volume) for the GTV and PTV; dose to the most exposed 2-cc volume (D2cc) for the D1-D2, D3-D4, and stomach [16]; and volume of the D1-D2, D3-D4, and stomach irradiated with >10 Gy (RBE) (V10), in the dose volume histograms (DVHs) for each

Table 1
Target volumes.

Target volume (cc)	Supine		Prone	
	Mean ± SD	(Min,Max)	Mean ± SD	(Min,Max)
Pancreatic head (n = 15)				
GTV	14.7 ± 16.3	(3.6,67.6)	12.0 ± 14.3	(2.4,59.1)
PTV	195.7 ± 6.3	(95.0,299.7)	198.9 ± 58.6	(97.9,278.8)
D1-D2	38.9 ± 21.2	(12.6,107.6)	31.0 ± 19.6	(10.4,86.6)
D3-D4	34.1 ± 11.7	(16.9,55.0)	29.8 ± 14.2	(10.4,58.3)
Stomach	164.9 ± 79.4	(55.6,294.0)	152.8 ± 93.5	(37.1,326.8)
Pancreatic body (n = 15)				
GTV	24.1 ± 14.1	(1.3,53.4)	21.5 ± 10.6	(3.3,40.0)
PTV	197.7 ± 61.4	(104.6,280.3)	200.3 ± 56.3	(107.0,277.5)
D1-D2	33.0 ± 19.4	(8.6,66.8)	27.0 ± 19.5	(4.5,65.8)
D3-D4	42.9 ± 36.2	(17.1,155.3)	38.5 ± 26.4	(16.6,123.3)
Stomach	171.4 ± 64.5	(60.5,296.8)	174.0 ± 76.0	(53.9,293.2)
Pancreatic tail (n = 3)				
GTV	32.0±.7	(21.2,52.4)	24.9 ± 16.3	(11.2,43.0)
PTV	179.5 ± 38.5	(150.8,223.2)	183.4 ± 37.2	(151.6,224.3)
D1-D2	45.6 ± 17.6	(33.5,65.8)	43.0 ± 21.2	(28.2,67.3)
D3-D4	28.7 ± 13.1	(19.3,43.7)	29.4 ± 2.5	(27.2,32.0)
Stomach	151.6 ± 127.4	(27.0,281.6)	173.8 ± 101.5	(75.7,278.4)
Total (n = 33)				
GTV	20.5 ± 16.1	(1.3,67.6)	17.5 ± 13.5	(2.4,59.1)
PTV	195.1 ± 59.3	(95.0,299.7)	198.1 ± 54.7	(97.9,278.8)
D1-D2	36.8 ± 19.9	(8.6,107.6)	30.2 ± 19.6	(4.5,86.6)
D3-D4	37.6 ± 25.9	(16.9,155.3)	33.7 ± 20.3	(10.4,123.3)
Stomach	166.6 ± 75.0	(27.0,296.8)	164.3 ± 84.3	(37.1,326.8)

Abbreviations: GTV, gross tumor volume; PTV, planning target volume; D1-D2, 1st-2nd portion of duodenum; D3-D4, 3rd-4th portion of duodenum; n, number of patients; SD, standard deviation; Min, minimum; Max, maximum.

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