Impact of organ deformation on ablative treatment of pancreatic cancer

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INTRODUCTION

For locally advanced unresectable pancreatic cancer (LAPC), conventional doses of radiation are not effective to improve long-term survival, and stereotactic body radiotherapy (SBRT) or hypofractionated ablative radiotherapy (in 15–25 fractions) has shown promising local control with an acceptable rate of adverse events[1, 2]. Ablative hypofractionation incorporates the precision of SBRT technique into a more protracted course, intensifying dose in LAPC. However, the pancreas is in proximity to several critical structures such as duodenum, stomach, kidneys, and spinal cord[3]. Thus our treatment plans strategically cover as much of the tumor as possible with an ablative dose while restricting the areas directly abutting the gastrointestinal (GI) tract to safe doses used in conventional radiotherapy. Specifically, the high dose planning target volume was expanded from the gross tumor volume (GTV) but with all organs at risk (OARs) excluded with an additional margin of 5–7 mm. As a result, the high dose coverage on the GTV was a secondary priority to OAR sparing, which became more vulnerable to the daily variation of GI anatomy.

AIM

To quantify the impact of organ deformation on the ablative treatment for pancreatic cancer.

METHODS

We retrospectively analyzed fourteen patients treated with volumetrically-modulated arc therapy in 2017–2019 for pancreatic cancer. Thirteen patients each had one or more fiducial markers attached to the target and matched by image guidance for treatments. The other one patient was treated with bone match. We generated 72 virtual computed-tomography scans (vCT) by deforming planning CTs (pCT) to cone beam CTs (CBCT). The number of full-FoV (field of view) CBCTs varied for each patient. Areas that were matched for treatment were used to guide the deformable registration through the Reg Refine function of the commercial software (MIM Version 6.9.7, MIM Software Inc., Cleveland, OH). Daily dose distributions on the vCT scans were calculated and mapped back to the pCT, where we characterized the daily target coverage by the highly sensitive parameter GTV $V_{100\%}$ (percentage of GTV receiving the full dose). The daily dose distributions of each patient were further summed up allowing evaluation of cumulative coverage and other relevant dosimetric quantities, which were compared with the treatment plans.

RESULTS

Table 1 shows the daily and cumulative coverage estimated from CBCT scans, compared to planned values. The median daily coverage was 65% (range 12–74%). The daily coverage varied by $<10\%$ (standard deviation, SD) for all patients except the bone-matching patient (Patient 12), for whom the SD was 29%. The median cumulative coverage was 58% (range 6–74%), compared to median 79% (range 10–96%) from the original plans.

Table 1: Daily and cumulative coverage estimated from CBCT scans, compared to planned values.

Patient number	GTV $V_{100\%}$ Planned	Daily average	Cumulative	Number of CBCT scans analyzed
1	92%	72%	72%	1
2	96%	74%	74%	1
3	83%	70%	58%	6
4	20%	12%	12%	1
5	79%	64%	62%	6
6	80%	27%	21%	2
7	90%	74%	73%	3
8	51%	34%	34%	1
9	20%	17%	17%	1
10	72%	65%	65%	1
11	83%	65%	65%	1
12	94%	52%	6%	25
13	65%	66%	58%	9
14	10%	13%	8%	2

Abbreviations: CBCT = cone beam computed tomography; GTV = gross tumor volume.

The cumulative target coverage of Patient 12 degraded by the largest amount (88% drop). For that patient, the cumulative stomach dose was 62 Gy, which was 5 Gy higher than the planned value and exceeded our limit of 60 Gy (Table 2).

For Patient 6, the image registration was significantly affected by the CBCT artifacts.

CONCLUSIONS

Organ deformation significantly affected target coverage for ablative treatment of pancreatic cancer. Daily image guidance with internal marker localization provided some mitigation but is limited by the drawbacks of CBCT imaging.

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Table 2: Comparison of dose-volume metrics for Patient 12.

	PTV$_{45\,Gy}$			PTV$_{75\,Gy}$			Small bowel		Stomach		Large bowel	Liver (non-GTV)		Cord	Right kidney	Left kidney
	$D_{95\%}$	$V_{100\%}$	D_{max}	$D_{95\%}$	$V_{100\%}$	D_{max}	D_{max}	$V_{45\,Gy}$	D_{max}	$V_{50\,Gy}$	D_{max}	$V_{<28\,Gy}$	D_{mean}	D_{max}	$V_{20\,Gy}$	
Goal/constraint	100%	90%		100%	90%	110%	55 Gy	40 cm^3	60 Gy	40 cm^3	65 Gy	700 cm^3	28 Gy	45 Gy	33%	33%
Planned	102%	98%	176%	96%	79%	110%	51 Gy	6 cm^3	57 Gy	5 cm^3	39 Gy	1566 cm^3	9 Gy	18 Gy	11%	10%
Cumulative	69%	68%	168%	62%	4%	102%	44 Gy	0	62 Gy	5 cm^3	30 Gy	1553 cm^3	11 Gy	17 Gy	5%	5%

Abbreviations: PTV = planning target volume; GTV = gross tumor volume.