Scientific Article

Quantifying and Assessing the Dosimetric Impact of Changing Gas Volumes Throughout the Course of VMAT Radiation Therapy of Upper Gastrointestinal Tumors

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Abstract

Purpose: This retrospective patient study assessed the consistency of abdominal gas presence throughout radiation therapy for patients with upper gastrointestinal cancer and determined the impact of variations in gas volume on the calculated dose distribution of volumetric modulated arc therapy.

Methods and Materials: Eight patients with pancreatic cancer were included for analysis. A plan library consisting of 3 reference plans per patient ($Ref_{0.0}$, $Ref_{0.5}$, and $Ref_{1.0}$) was created based on planning computed tomography (CT) with density overrides of 0.0, 0.5, and 1.0 applied to gas volumes, respectively. Corresponding cone beam CT (CBCT) data sets were obtained and density overrides were applied to enable fractional dose calculation. Variation in gas volume relative to initial volume determined from CT was assessed. Dose metrics for targets and organs at risk were compared between the accumulated CBCT dose and the planned dose of the 3 reference plans for each patient.

Results: There was a significant decrease in gas present from CT to treatment CBCT, with a mean decrease in volume of 48.6% for the entire cohort. Dosimetrically, all accumulated target and organ-at-risk parameters, aside from the kidneys, exhibited the smallest mean deviation from the $Ref_{0.0}$ plan and largest mean deviation from the $Ref_{1.0}$ plan. A statistically significant difference in mean accumulated dose to $Ref_{0.0}$ and $Ref_{1.0}$ was observed for the dose delivered to 95% of the planning target volume.

Conclusions: Significant variation in gas volumes from CT to treatment can occur throughout volumetric modulated arc therapy for pancreatic cancer. Through the use of a plan library, it was determined that initial assessment of a patient's treatment plan with an assigned gas density of 0.0 provided the most accurate prediction of the accumulated dose.

Introduction

Patients with pancreatic cancer typically present with advanced stages of disease and therefore rarely undergo surgical resection with curative intent.[1] Highly conformal radiation therapy techniques, such as volumetric modulated arc therapy (VMAT) and stereotactic body radiation therapy, have enabled the improvement of local control with a decreased incidence of severe adverse effects seen with older radiation therapy techniques.[2-4] As treatment becomes more conformal and precise, the potential for dosimetric errors as a result of geometric uncertainties increases.[4,5]

Gas volumes have been reported to result in both a decrease and increase in delivered dose at their proximal and distal interfaces, respectively.[6,7] Therefore, there is potential for the underdosing of target volumes and overdosing of organs at risk (OARs) (eg, bowel, duodenum and stomach) when the size and location of gas volumes in the upper gastrointestinal tract (GI) changes throughout treatment.

Research investigating the presence and dosimetric impact of changing gas volumes on radiation therapy treatment for upper GI tumors shows varying results.[8-14] Interfractional fluctuations in gas volumes have been found to be significant during pancreatic irradiation.[8-10] Although some studies have found significant variations in delivered dose to target volumes and OARs, they fail to report on the treatment delivery techniques used and only assess the impact of gas on a weekly[13] and single-fraction[14] basis. The few studies sourced on VMAT have shown changes in gas volume to have a minimal dosimetric effect across a cohort of 9 pancreatic patients.[10,12] These studies focus on short-course radiation therapy treatment (ie, 15 fractions). However, gas changes may present differently over long-course treatments (ie, 30 fractions).

The primary aim of this study was to investigate the consistency in presence and size of gas volumes throughout long-course treatment of patients with upper GI cancer and determine the extent to which variations in gas volume alter the planned dose for both target volumes and OARs in VMAT pancreatic radiation treatments. From this, we determined whether assessing a treatment plan with or without a gas density override before treatment provided a more accurate estimation of the total accumulated dose.

Methods and Materials

Patient selection and imaging

This retrospective study was approved by the ethics committee of South Western Sydney Local Health District. The sample consisted of 10 patients who underwent radical VMAT radiation therapy for pancreatic cancer at Liverpool and Macarthur Cancer Therapy Centres between September 2017 and May 2019. Patients required a long course of treatment (25 or more fractions), a planning CT scan acquired with a Philips CT Big Bore (Philips, Eindhoven, The Netherlands), and a complete set of daily cone beam computed tomography (CBCT) images. Dual arc 6MV VMAT treatment plans were created in the treatment planning system (TPS) (Pinnacle, version 16.0, Philips). Each patient was treated on a linear accelerator with on-board CBCT (Elekta Versa HD, Elekta AB, Stockholm, Sweden). The CBCT images were transferred from the online imaging system (XVI, Elekta AB) to the TPS. Each patient's body mass index (BMI) and initial weight were noted, as registered in the radiation oncology information system (MOSAIQ, Elekta AB). No pretreatment dietary advice was given to patients.

CBCT registration and dose calculation

In the TPS, each CBCT was fused to its respective planning CT using rigid registration, matching to the vertebral bodies adjacent to the target location. Target structures, OARs, and the treatment isocenter were imported and reassigned from the original treatment plan for each CBCT. A CBCT density segmentation script was used to automatically delineate bone and gas on all axial slices between 2 cm superior and 2 cm inferior to the planning target volume (PTV) and soft tissue on all axial slices between 5 cm superior and 5 cm inferior to the PTV using standardized CBCT threshold settings (minimum Hounsfield units [HU] of 800 [bone] and 550 [gas]). Owing to the lack of accurate CBCT HU,[10] bulk density overrides of 1.8, 1.0, and 0.0 were assigned to bone, soft tissue, and gas volumes, respectively, to enable dose calculations (Fig 1). VMAT beam data were transferred from the patients' treatment plan to their CBCT data sets and recalculated to a fractional dose. Each patient's calculated CBCT data sets were then summed to provide a total accumulated dose for treatment.

Creation of reference plans

A plan library consisting of 3 reference plans per patient (Ref$_{0.0}$, Ref$_{0.5}$, and Ref$_{1.0}$) was created by copying the original planning CT data set. Bone, gas, and soft tissue were delineated to the same limits as described for the CBCT plans using auto-segmentation tools with standardized CT threshold settings (minimum HU value of 1150 [bone] and 700 [gas]). Density overrides were also applied to each reference plan, as described for the CBCT plans, with the exception of gas volumes, which were assigned a density of 0.0, 0.5, and 1.0 on all Ref$_{0.0}$, Ref$_{0.5}$, and Ref$_{1.0}$ plans, respectively. The gas density
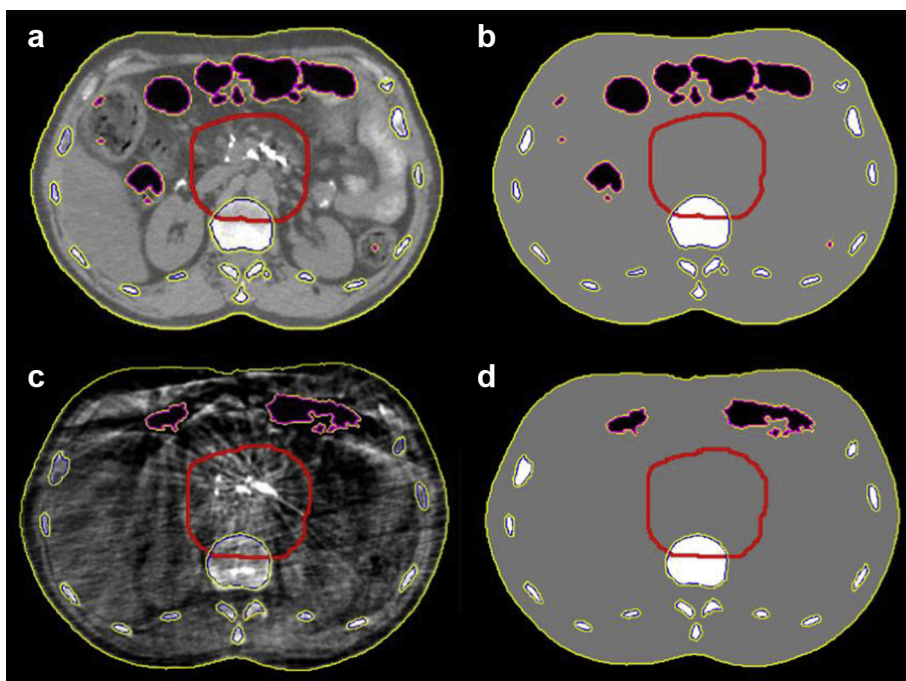
Figure 1 (a) Reference plan. (b) Reference plan with density overrides applied to bone, soft tissue, and gas contours. (c) Fraction 1 cone beam computed tomography. (d) Fraction 1 cone beam computed tomography with density overrides applied. Lines show bone (dark blue), soft tissue (yellow), gas (pink), and planning target volume (red). (A color version of this figure is available at https://doi.org/10.1016/j.adro.2021.100650.)

overrides were created to present the potential extremes within a patient's plan. An override of 0.0 represents pure air in the structure, 1.0 represents pure water or soft tissue in the structure (eg, empty stomach or collapsed bowel), and 0.5 represents potential averaging of air or soft-tissue density. All plans were then recalculated (not reoptimized) using the adaptive convolution algorithm in the TPS, as shown in Figure 2.

Structures created for the volumetric analysis of gas

Further gas volumes were delineated on all reference plans and CBCT plans to facilitate volumetric analysis. The reference plan gas volume previously described was copied using Boolean operations to create the planning gas volume (GAS_P). This contour was edited within the limits of 1 cm superior and 1 cm inferior to the PTV. This same process was used for the gas on each CBCT plan to create CBCT gas volumes (GAS_C).

Volumetric and dosimetric analysis

Dose-volume histogram files for GAS_P and GAS_C, as well as for the targets and OARs (as listed in Table 1),

were exported from the TPS to MATLAB (MathWorks, Natick, MA), where an in-house program extracted the required dose volume metrics (also listed in Table 1). These metrics were then exported into Excel (Microsoft, Redmond, WA) spreadsheets for analysis.

Metric and statistical analysis

Dosimetric and volumetric data were tested for statistical significance using SPSS (IBM Corporation, Armonk, NY). Wilcoxon signed-rank tests tested for significant differences between GAS_P and mean GAS_C across the cohort. A Pearson correlation test was used to test for a relationship between GAS_P and differences in mean GAS_C. One-way analysis of variance tested for significant differences between the mean fractional dose metrics and the mean planned dose metrics of the $Ref_{0.0}$, $Ref_{0.5}$, and $Ref_{1.0}$ plans for all patients. A Pearson correlation test was used to test for a relationship between relative changes in mean GAS_C and changes in the accumulated dose metrics for target structures.

Patients' BMI and weight were assessed using independent t tests and Pearson correlation tests to determine whether they had a relationship with the volume of GAS_P and GAS_C. For all statistical analyses, 2-sided tests were
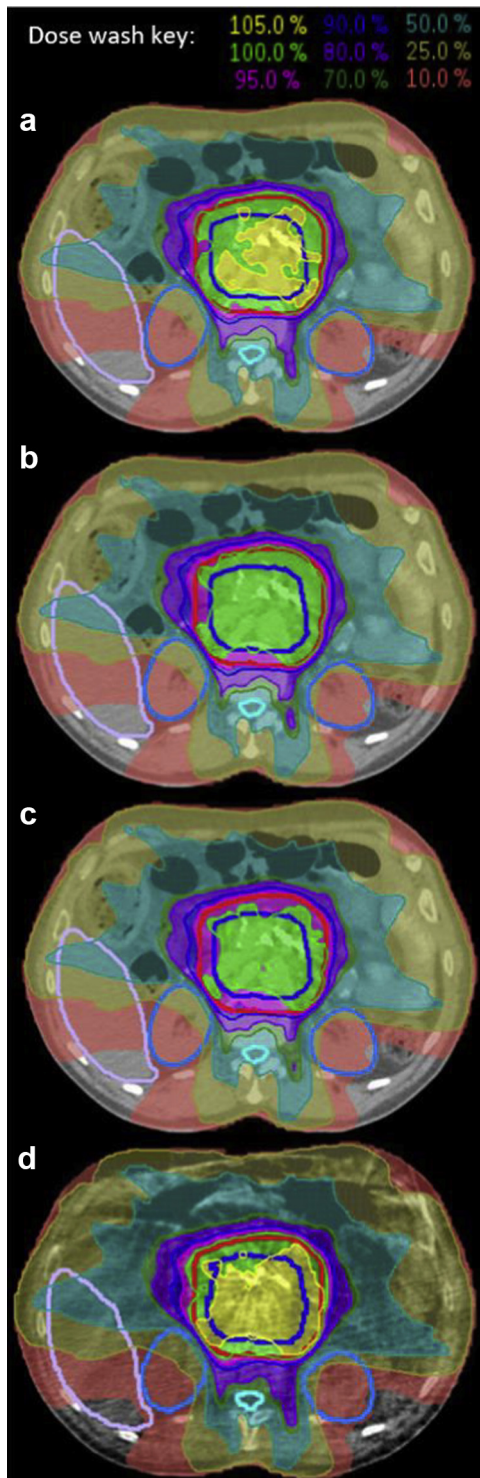
Figure 2 Dose distributions of (a) reference plan with gas override of 0.0, (b) reference plan with gas override of 0.5, (c) reference plan with gas override of 1.0, and (d) fraction 1 cone beam computed tomography for the same patient. Thick lines show clinical target volume (dark blue), planning target volume (red), kidneys (light blue), spinal cord (sky blue), and liver (lavender). (A color version of this figure is available at https://doi.org/10.1016/j.adro.2021.100650.)

Table 1 Target and OAR volumes and dose volume metrics assessed

Volume	Dose volume metrics assessed
GAS_P	Volume (cm^3)
GAS_C	Volume (cm^3)
CTV	D50; dose to 50% volume
	D95; dose to 95% volume
PTV	D50; dose to 50% volume
	D95; dose to 95% volume
Spinal cord	Max; maximum dose delivered
Liver minus GTV	Mean; mean dose delivered
	V33; volume receiving 33% of prescribed dose
Right kidney	Mean; mean dose delivered
	V33; volume receiving 33% of prescribed dose
Left kidney	V6; volume receiving 6% of prescribed dose
Small bowel	Max; maximum dose delivered
Stomach PRV	Max; maximum dose delivered
Duodenum PRV	Max; maximum dose delivered

Abbreviations: CTV = clinical target volume; GAS_C = cone beam computed tomography gas volume; GAS_P = planning gas volume; GTV = gross tumor volume; OAR = organ at risk; PRV = planning organ at risk volume; PTV = planning target volume.

applied, and *P* values <.05 were considered statistically significant.

Results

Patient characteristics

Two patients were excluded from the study because their CBCT scans had been acquired with a small field of view, resulting in incomplete patient contour data. Six individual CBCT images were also excluded from analysis, 5 owing to having a limited field of view and 1 owing to high levels of artefact, preventing accurate delineation of gas. This resulted in a total of 225 available CBCT images for analysis. Patient characteristics are presented in Table 2.

Volumetric analysis of gas

Gas volume present on planning CT (GAS_P) ranged from 12.9 to 497.1 cm^3 with a mean volume of 137.7 cm^3 (Table 3). In contrast, the volume on CBCT (GAS_C) ranged from 0.3 to 327.5 cm^3 with a mean volume of 56 cm^3. Testing found a statistically significant difference between mean GAS_P and mean GAS_C (*P* = .012). On average, there was a 48.6% decrease in gas volume from CT to CBCT for all patients. In total, 202 of 225 (89.8%)

Table 2   Patient characteristics

Patient ID	Sex	Age	Diagnosis	Dose regimen	CBCT scans analyzed, n	BMI	Initial weight, kg
2	F	61	Pancreas, part unspecified	30 × 1.8 Gy	30	24.4	64
3	F	52	Head of pancreas	28 × 1.8 Gy	28	21.3	61
4	M	59	Head of pancreas	28 × 1.8 Gy	28	24.7	79
5	F	39	Head of pancreas	27 × 2 Gy	27	30.5	79
6	F	67	Head of pancreas	30 × 1.8 Gy	29[a]	24.2	53
7	M	76	Head of pancreas	28 × 1.8 Gy	25[a,b]	N/A[c]	45
8	M	51	Head of pancreas	30 × 1.8 Gy	29[a]	24.1	73

Abbreviations: BMI = body mass index; CBCT = cone beam computed tomography; F = female; M = male.
   [a] The number of CBCT scans assessed was reduced owing to the exclusion of CBCT images acquired with a small field of view.
   [b] The number of CBCT images assessed was reduced owing to the exclusion of a CBCT acquired with high levels of artefact.
   [c] BMI data not available.

Table 3   Gas volume metrics of GAS_P and GAS_C for all patients (N = 8)

Patient ID	Gas volume (cm³)			Mean GAS_C difference, %
	GAS_P	Mean (range) GAS_C	Δ from GAS_P to GAS_C	
1	32.3	23.7 (5.4-78.4)	−8.7	−26.8
2	128.7	88.0 (29.9-172.3)	−40.7	−31.6
3	107.0	32.1 (4.3-172.3)	−74.8	−70.0
4	497.1	138.1 (21.3-327.5)	−359.0	−72.2
5	12.9	10.3 (0.3-39.5)	−2.7	−20.7
6	72.4	27.6 (2.3-69.1)	−44.8	−61.9
7	86.3	30.8 (7.8-81.7)	−55.5	−64.3
8	164.8	97.2 (17.9-273.0)	−67.6	−41.0
Average	137.7	56.0	−81.7	−48.6

Abbreviations: Δ = absolute change in value; GAS_C = cone beam computed tomography gas volume; GAS_P = planning gas volume.

CBCT images presented with a GAS_C less than that on their respective planning CT, as depicted in Figure 3. Individual patient differences in GAS_C are displayed in Figure 4. Patient 4 had the greatest GAS_P (497.1 cm³) and exhibited the greatest mean difference in GAS_C (−72.2%); patient 5, who presented with the smallest GAS_P (12.9 cm³), exhibited the smallest mean difference in GAS_C (−20.7%). Testing found no significant relationship between GAS_P and differences in mean GAS_C (P = .175). A significant moderate to strong positive linear relationship between relative differences in mean GAS_C and patient BMI was found (P = .046; r = 0.764).

Dosimetric analysis

All dose-volume metrics were reported as proportional doses, as displayed in Table 4. For all reference plan target and OAR parameters, mean planned dose metrics decreased as the gas density increased. Accumulated CBCT doses for all clinical target volume (CTV) and

PTV target parameters showed the smallest deviation from the planned dose of the $Ref_{0.0}$ plan (0.5%-0.8% increase), compared with the $Ref_{0.5}$ and $Ref_{1.0}$ plans. The accumulated dose for all OAR parameters, aside from the kidneys, also exhibited on average the smallest deviation from the planned dose of the $Ref_{0.0}$ plan. Right and left kidney parameters displayed the smallest deviations from the $Ref_{0.5}$ and $Ref_{1.0}$ plans, respectively. One example—patient 4, who had the largest gas volume and absolute variation during treatment—is provided as Figure E1.

The difference in the mean accumulated dose between $Ref_{0.0}$ and $Ref_{1.0}$ was determined to be statistically significant for PTV D95 (0.5% and 2.1%, respectively; P = .042). All other parameter differences were deemed insignificant.

Discussion

Conformal radiation therapy techniques, such as VMAT, are increasingly used for the treatment of pancreatic cancer.[4,5,7] However, the implementation of VMAT brings uncertainties regarding the accumulated dose to the target volume and healthy organs, owing to variation in abdominal gas volumes.[7,8] This study sought to measure the fluctuations in abdominal gas volumes throughout the course of VMAT radiation therapy for pancreatic cancer and determine the dosimetric impact of such interfractional changes on both target and OAR coverage.

Multiple studies have found that deviations in delivered dose occur in patients with upper GI cancer who present with varying abdominal gas volumes throughout treatment.[9,11,13,14] However, these studies either fail to report on the treatment technique used, assess intensity modulated radiation therapy, or simply determine their dosimetric differences to be clinically acceptable. The results of the few studies to focus on VMAT treatment delivery[10,12] provide support to the findings outlined in
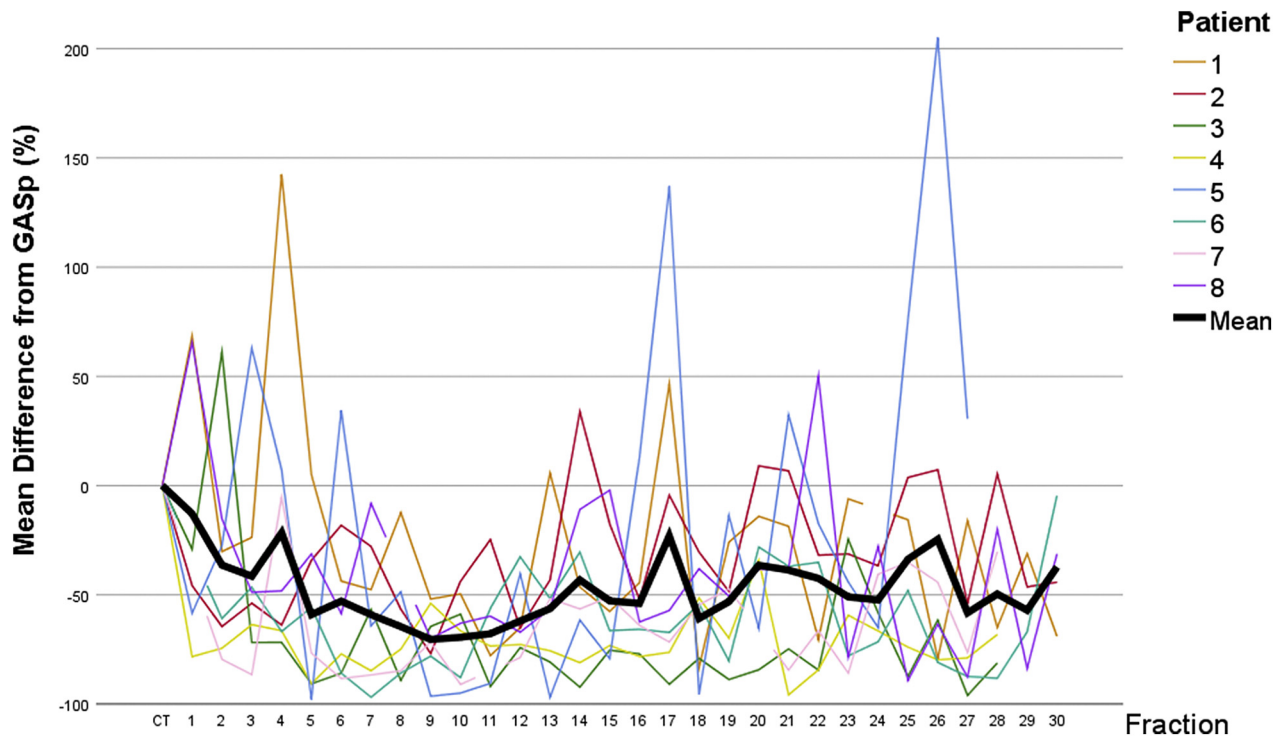
Figure 3   Relative difference (%) from planning gas volume to all daily cone beam computed tomography gas volumes.
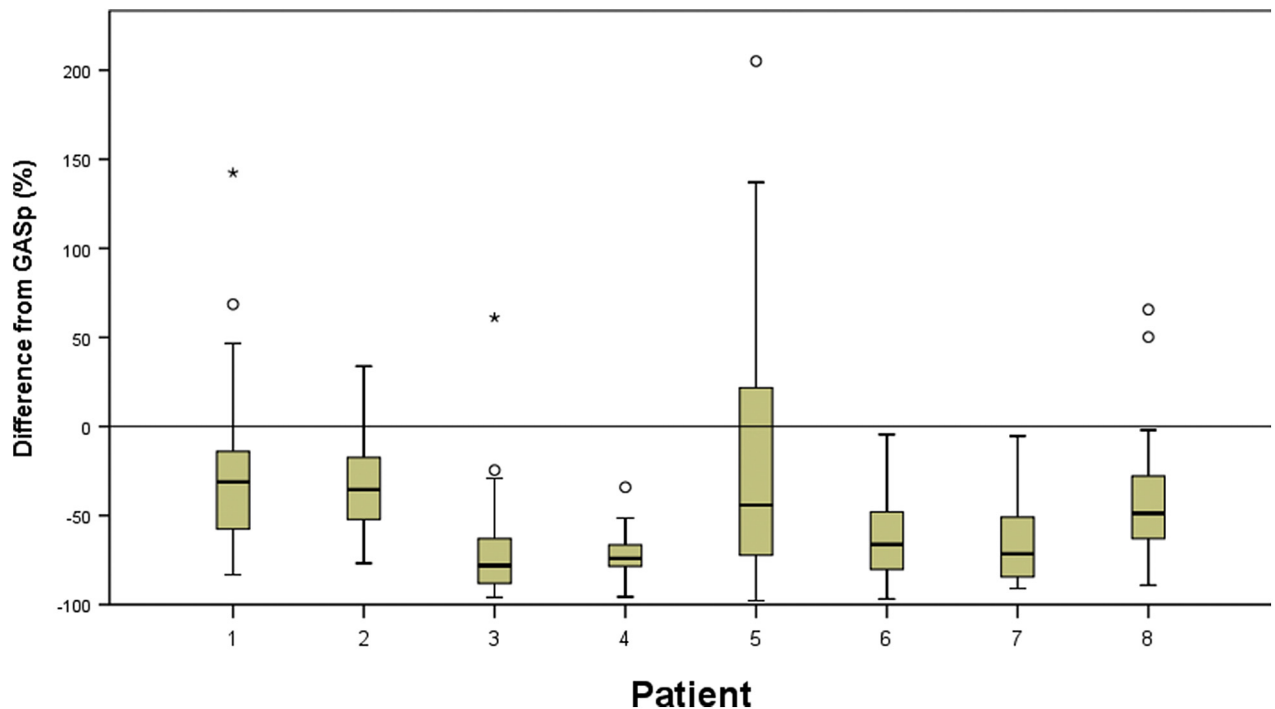

Figure 4   Relative cone beam computed tomography gas volume differences (%) from planning gas volume for each patient. Circles represent outliers, and stars represent extreme outliers.

the present study. Van der Horst et al[10] and Houweling et al[12] both found variations in gas volume throughout treatment to have a minimal dosimetric impact, with Houweling et al[12] finding differences between planned and delivered dose metrics for both target volumes and OARs to be less than 0.5%. These studies focused on short-course radiation therapy; therefore, the dosimetric impacts reported may not be representative of a higher

Table 4 DVH parameters (mean and range over all 8 patients) for the 3 reference plans ($Ref_{0.0}$, $Ref_{0.5}$, and $Ref_{1.0}$) and CBCT plans

Volume	DVH parameter	$Ref_{0.0}$	$Ref_{0.5}$	Mean (range) planned dose/volume, %		Mean (range) accumulated dose/volume, %			
				$Ref_{1.0}$	CBCTs	Δ from $Ref_{0.0}$	Δ from $Ref_{0.5}$	Δ from $Ref_{1.0}$	Closest plan
CTV	D50	104.2 (102.7-105.7)	103.5 (102.1-105.1)	102.8 (101.1-104.9)	105.0 (103.4-108.6)	0.8 (−1.1 to 3.3)	1.4 (−0.1 to 3.6)	2.1 (0.3-3.7)	$Ref_{0.0}$
	D95	99.4 (97.2-101.5)	98.8 (96.9-101.3)	98.0 (96.0-100.9)	100.1 (97.0-102.4)	0.7 (−1.7 to 2.7)	1.4 (0.2-3.4)	2.1 (0.6-4.0)	$Ref_{0.0}$
PTV	D50	103.4 (102.1-104.7)	102.8 (101.6-104.3)	102.1 (100.4-104.0)	104.2 (102.5-107.6)	0.8 (−0.6 to 3.1)	1.4 (−0.2 to 3.4)	2.1 (0.2-3.6)	$Ref_{0.0}$
	D95	98.0 (95.2-100.4)	97.5 (94.8-100.6)	96.4 (94.2-99.9)	98.5 (94.4-101.4)	0.5[a] (−1.2 to 2.3)	1.1 (−0.4 to 2.8)	2.1[a] (0.2-3.8)	$Ref_{0.0}$
Spinal cord	Max	51.0 (9.4-81.1)	50.6 (9.4-80.6)	50.3 (9.4-80.1)	51.5 (10.1-81.5)	0.5 (−1.3 to 2.0)	0.8 (0.2-2.0)	1.2 (0.3-2.3)	$Ref_{0.0}$
Liver GTV	Mean	25.4 (9.4-40.9)	25.3 (9.4-40.9)	25.2 (9.4-40.9)	25.7 (9.8-41.4)	0.3 (−0.1 to 0.6)	0.4 (−0.0 to 0.7)	0.5 (0.0-0.8)	$Ref_{0.0}$
	V33	8.7 (0.8-16.5)	8.6 (0.8-16.4)	8.6 (0.8-16.3)	9.0 (1.1-17.0)	0.3 (−0.1 to 1.1)	0.3 (−0.0 to 1.1)	0.4 (0.0-1.1)	$Ref_{0.0}$
Right kidney	Mean	20.4 (4.5-36.1)	20.3 (4.5-35.8)	20.2 (4.5-35.6)	20.3 (4.6-36.0)	−0.1 (−0.7 to 0.2)	−0.0 (−0.4 to 0.4)	0.1 (−0.3 to 0.6)	$Ref_{0.5}$
	V33	2.8 (0.0-8.8)	2.7 (0.0-8.5)	2.6 (0.0-8.2)	2.7 (0.0-8.6)	−0.1 (−0.9 to 0.5)	-0.0 (−0.7 to 0.5)	0.1 (−0.4 to 0.5)	$Ref_{0.5}$
Left kidney	V6	61.6 (0.4-100.0)	61.5 (0.4-100.0)	61.5 (0.4-100.0)	61.3 (0.3-100.0)	−0.3 (−5.3 to 2.7)	−0.2 (−5.3 to 2.6)	−0.1 (−5.3 to 2.5)	$Ref_{1.0}$
Small bowel	Max	100.3 (94.3-105.1)	99.4 (93.8-103.4)	99.0 (93.2-102.6)	101.6 (96.5-104.9)	1.2 (−1.3 to 2.8)	2.1 (−0.5 to 3.5)	2.6 (0.2-4.4)	$Ref_{0.0}$
Stomach PRV	Max	105.3 (102.4-106.9)	104.5 (102.4-106.2)	104.0 (101.9-106.0)	106.9 (104.5-109.3)	1.7 (−1.2 to 3.9)	2.4 (1.5-4.0)	3.0 (1.5-4.1)	$Ref_{0.0}$
Duodenum PRV	Max	105.8 (104.5-107.3)	105.3 (104.5-106.1)	104.9 (104.2-105.9)	107.3 (105.0-109.4)	1.5 (−0.4 to 4.2)	2.0 (0.5-4.2)	2.4 (0.8-4.2)	$Ref_{0.0}$

Abbreviations: Δ = absolute change in value; CBCT = cone beam computed tomography; CTV = clinical target volume; D50 = dose to 50% volume; D95 = dose to 95% volume; DVH = dose-volume histogram; GTV = gross tumor volume; PRV = planning organ at risk volume; PTV = planning target volume; $Ref_{0.0}$ = reference plan with gas overridden with a density of 0.0; $Ref_{0.5}$ = reference plan with gas overridden with a density of 0.5; $Ref_{1.0}$ = reference plan with gas overridden with a density of 1.0; V6 = volume receiving 6% of prescribed dose; V33 = volume receiving 33% of prescribed dose.

[a] Δ from $Ref_{0.0}$ was significantly different from Δ from $Ref_{1.0}$ as determined by analysis of variance ($P < .05$).

fractionation radical treatment regimen. The similar range of results outlined in the present study do, however, suggest that VMAT is robust against the influence of changing gas volumes during long-course pancreatic treatment.

This study found large interpatient variability in the volume of gas present at CT, with the relevant gas volumes found to decrease significantly from CT to treatment across the entire cohort. Similar results are reported by Van der Horst et al,[10] who found gas to decrease significantly from CT to CBCT during short-course VMAT pancreatic treatment for 6 of their 9 patients. However, they reported no explanation for why this occurred. In this study, patient BMI was found to be significantly positively correlated with the average differences in daily gas volumes, with a lower BMI correlating with a greater decrease in gas. This result indicates that BMI may be used clinically as a predictive factor for differences in gas volume throughout treatment and when a patient may potentially be at risk of exhibiting large decreases in gas volumes. However, the findings of this study indicate that the dosimetric impact such differences in gas volume may cause are insignificant. A greater sample size and tracking of weight and BMI during the course of treatment may assist in providing more accurate measures of their influence on gas volumes. Reduction in gas volume from CT to treatment may also be influenced by the bowel side effects caused by treatment, but this was not assessed. Poor-quality CBCT images may also influence the ability of the TPS to accurately segment gas volumes.[10]

Mitigating the influence of changing gas volumes by applying density overrides to the gas volumes present at planning CT resulted in greater differences between the planned and accumulated doses. Accumulated CBCT doses showed the smallest dose metric deviations from the planned dose of the $Ref_{0.0}$ plan and the largest deviation from the planned dose of the $Ref_{1.0}$ plan for all target and OAR metrics, aside from the kidneys. Despite showing greater deviation from the $Ref_{0.0}$ plan (compared with $Ref_{0.5}$ and $Ref_{1.0}$ plans), the left and right kidney metrics still displayed very little deviation from the $Ref_{0.0}$ plan. Testing found no significant differences between the metrics of the reference plans, apart from the PTV D95, which showed a significant difference between the mean dose differences of the $Ref_{0.0}$ and $Ref_{1.0}$ plans. When analyzing data as a whole group, $Ref_{0.0}$ plans resulted in the least variation in the accumulated dose for the CTV and the majority of OARs for the whole treatment course. This indicates that despite significant variations in gas volume, treatment plans should be assessed before treatment without a gas density override (where gas density equals 0.0) to provide the most accurate prediction of total accumulated dose.

There are several limitations to this study. Given the low incidence of patients with pancreatic cancer who are prescribed radical radiation therapy and the relatively recent implementation of VMAT as a feasible treatment option, only 8 patients were available to review. This is a common limitation for studies investigating pancreatic cancer,[9-12] resulting in the inability to assess the true implications of changing gas volumes for VMAT treatment delivery. Greater collaboration between institutions and pooling of data sets may be a viable option to help improve sample size and the quality of results.

Inaccurate Hounsfield units of the CBCT images, preventing accurate dose calculation, was another limitation of this study. Density overrides were used to overcome this and were applied to all reference plans to create a like-for-like comparison. Others[10,12] have reported that there is minimal variation in soft-tissue density in the upper abdominal region, indicating a minimal effect of using bulk tissue density overrides on dose calculation accuracy. Poor CBCT quality does, however, result in uncertainty in the accuracy of gas segmentation and target and OAR delineation. To overcome this, all target and OAR structures were imported from the planning CT to the CBCT images after they were rigidly registered. Realistically, organ and target deformation would occur throughout the course of treatment. As a result, accumulated dose results are only an indication of the dosimetric impact on targets and OARs caused by changing gas volumes, not interfractional changes of the target and OARs themselves. Implementation of daily MRI imaging may provide greater visualization of organs and gas volumes and enable more accurate fractional dose calculation. Deformable image registration and adaptive planning may also be helpful tools to overcome these issues.

Although the results of this study may improve clinical decision making with regard to VMAT treatment planning for patients with pancreatic cancer presenting with varying gas volumes, further study may be required into the effect of gas on more highly conformal hypofractionated treatment techniques such as stereotactic body radiation therapy.

Conclusion

Significant variation in gas volumes from planning CT to treatment can occur. The impact of daily gas variation on the planned dose coverage is minimal during the total course of a pancreatic cancer VMAT treatment. Through the use of 3 separate reference plans ($Ref_{0.0}$, $Ref_{0.5,}$ and $Ref_{1.0}$), it was determined that assessing a patient's treatment plan with no gas density overrides provided the most accurate prediction of the delivered dose for the majority of patients. For SBRT or individual patients with gas in close proximity to the target volume or with very large variation, adaptive planning may still be of benefit.

Supplementary Materials

Supplementary material for this article can be found at https://doi.org/10.1016/j.adro.2021.100650.

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