Restricted bowel loop contouring: Improving efficiency in radiotherapy contouring for abdomino-pelvic Stereotactic Ablative Radiotherapy (SABR)

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ABSTRACT

We present a time-saving alternative to individual bowel loop delineation for abdomino-pelvic Stereotactic Ablative Radiotherapy. Here, individual bowel loop contouring is only performed within a 3 cm circumferential and 2 cm superio-inferior expansion of the PTV. A bowel bag structure represents distal bowel. No relevant doses are 'missed' with this time-saving strategy.

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1. Introduction

There is increasing interest in the use of Stereotactic Ablative Radiotherapy (SABR) for treating nodal, bone and liver oligometastases in the abdomino-pelvic region. While data demonstrates that such an approach results in encouraging local control and suggests potential benefits in terms of progression free survival [1,2], these previously unirradiated or simply irradiated patients now receive complex radiotherapy treatments, thus increasing workloads across the radiotherapy pathway.

UK guidelines specify organ at risk (OAR) constraints for the small bowel (a point maximum and doses to 5 cm^3 and 10 cm^3) and colon (a point maximum) [3]. In many institutions, including our own, this is applied to individual bowel loops, thus mandating that all individual bowel loops are delineated on all planning CT slices that contain the PTV and on all slices for approximately 2 cm above and below the PTV to allow adequate dose representation on the radiotherapy plan. Narrow slice CT scans are employed for SABR treatments (usually 1 mm or 2 mm thickness), thus multiple slices must be delineated and interpolation tools within planning systems, designed to hasten contouring, are often imperfect

for complex structures such as the bowel. Contouring individual bowel loops for SABR planning is therefore a time-consuming process, often taking at least one hour based on local experience. Intuitively the highest doses will be delivered to loops of bowel in closest proximity to the target, calling into question the value of the time spent delineating bowel loops across the entirety of each CT slice.

This report aims to demonstrate the validity of contouring only those individual bowel loops in closest proximity to the target, while using the bowel bag to represent the dose received by those bowel loops positioned further from the target.

2. Methods

This retrospective study used datasets from 20 patients who received SABR for oligometastatic abdomino-pelvic nodal disease at Leeds Cancer Centre between July 2016 and October 2018. All patients received a prescription dose of 30 Gy in 5 fractions. No margin was added to the GTV to form the CTV (i.e. GTV = CTV) and a 5 mm isotropic margin was added to create the PTV. Individual bowel loops (colon delineated separately from small bowel) had been previously contoured on all slices covering the PTV and for 2 cm above and below the PTV, as part of the normal planning process (Fig. 1a). Small bowel constraints consisted of: maximum dose (to 0.5 cm^3; Dmax0.5cm^3): 30 Gy (optimal) or 35 Gy

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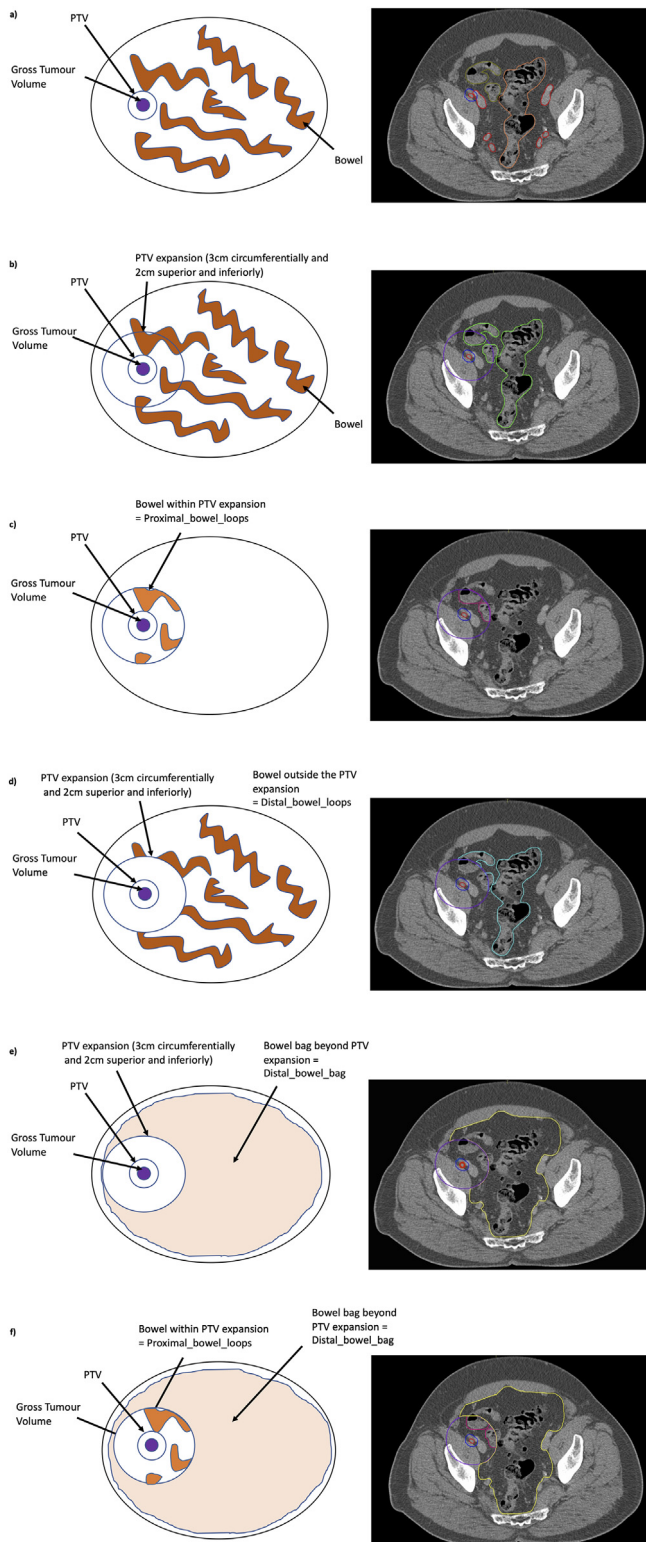
Fig. 1. a) Current solution (all bowel loops contoured), b) Defining proximal vs. distal bowel loops, c) Proximal bowel loops, d) Distal bowel loops, e) Distal bowel bag and f) Proposed contouring solution.

(mandatory) in 5 fractions. In addition, the dose limit to the hottest 5 cm^3 of small bowel (D5cm^3) was 25 Gy in 5 fractions (optimal) but could be relaxed such that the dose to the hottest 10 cm^3 of small bowel (D10cm^3) was 25 Gy in 5 fractions (mandatory). For the colon, Dmax0.5 cm^3 was 32 Gy (optimal) and 38 Gy (mandatory) in 5 fractions.

3. Structure segmentation

All segmentation was performed using Monaco (Version 5.1, Elekta AB, Stockholm, Sweden). For the purposes of this project, individual small bowel and colon loops were combined to form an 'All_bowel_loops' structure. The bowel loops considered as being in closest proximity to the target were those contained within a 3 cm circumferential and 2 cm superio-inferior expansion of the PTV (Fig. 1b). This margin was applied to the PTV and the intersection of this and all bowel loops within this volume were labelled 'Proximal_bowel_loops' (Fig. 1c). Bowel loops beyond those contained within the 3/2cm PTV expansion (i.e. non-Proximal_bowel_loops) were labelled as 'Distal_bowel_loops' (Fig. 1d). The bowel bag was then contoured on all slices from 2 cm above to 2 cm below the PTV, using the RTOG atlas for guidance[4]. The 3/2cm expansion around the PTV was subtracted from the bowel bag structure to create the 'Distal_bowel_bag' (Fig. 1e).

4. Dosimetric analysis

The maximum doses (to 0.5 cm^3; Dmax0.5cm^3) and doses to the hottest 5 cm^3 (D5cm^3) and 10 cm^3 (D10cm^3) of the following structures were evaluated:

- Proximal_bowel_loops (Fig. 1c)
- Distal_bowel_loops (Fig. 1d)
- Distal_bowel_bag (Fig. 1e)
- All_bowel_loops (Fig. 1a)

4.1. Statistics

Spearman's Rho (r) assessed potential monotonic correlations between bowel doses to the Distal_bowel_bag and Distal_bowel_-loops. The Wilcoxon-Signed Rank Test was used to compare Dmax0.5 cm^3, D5cm^3 and D10cm^3 between Proximal_bowel_loops and Distal_bowel_loops.

5. Approvals

The project was reviewed and approved by the local Research and Innovation Department, who considered it as a service evaluation project.

6. Results

Doses to Proximal_bowel_loops were significantly higher than doses to Distal_bowel_loops (p < 0.001 for Dmax0.5cm^3, D5cm^3 and D10cm^3), reflecting that bowel loops closest to the target are those that receive the highest doses and are therefore most critical for planning based on maximum dose and 'hot' dose constraints, as are commonly used for SABR. In keeping with this finding, the vast majority of dose metrics were higher for Proximal_bowel_loops than for Distal_bowel_loops. For Dmax0.5cm^3, as expected, the dose to Proximal_bowel_loops was higher in all cases (Proximal_bowel_loops minus Distal_bowel_loops median (and range): 15.4 (1.71–21.4)Gy (Fig. 2a). In one case, D10cm^3 was higher (by 0.7 Gy) for the Distal_bowel_loops than for the Proximal_bowel_loops. In one other case, both the D5cm^3 and D10cm^3 were higher to the Distal_bowel_loops than for the Proximal_bowel_loops (by 0.1 Gy and 2.4 Gy respectively). In both these cases, however, the absolute values were well within tolerance levels (Proximal_bowel_loops vs. Distal_bowel_loops: Case 1: D10cm^3: 6.5 Gy vs. 7.2 Gy; Case 2: D5cm^3 and D10cm^3: 10.7 Gy vs. 10.8 Gy and 7.6 Gy vs. 9.9 Gy respectively) and were adequately reflected by the dose received by the Distal_bowel_bag (see below).
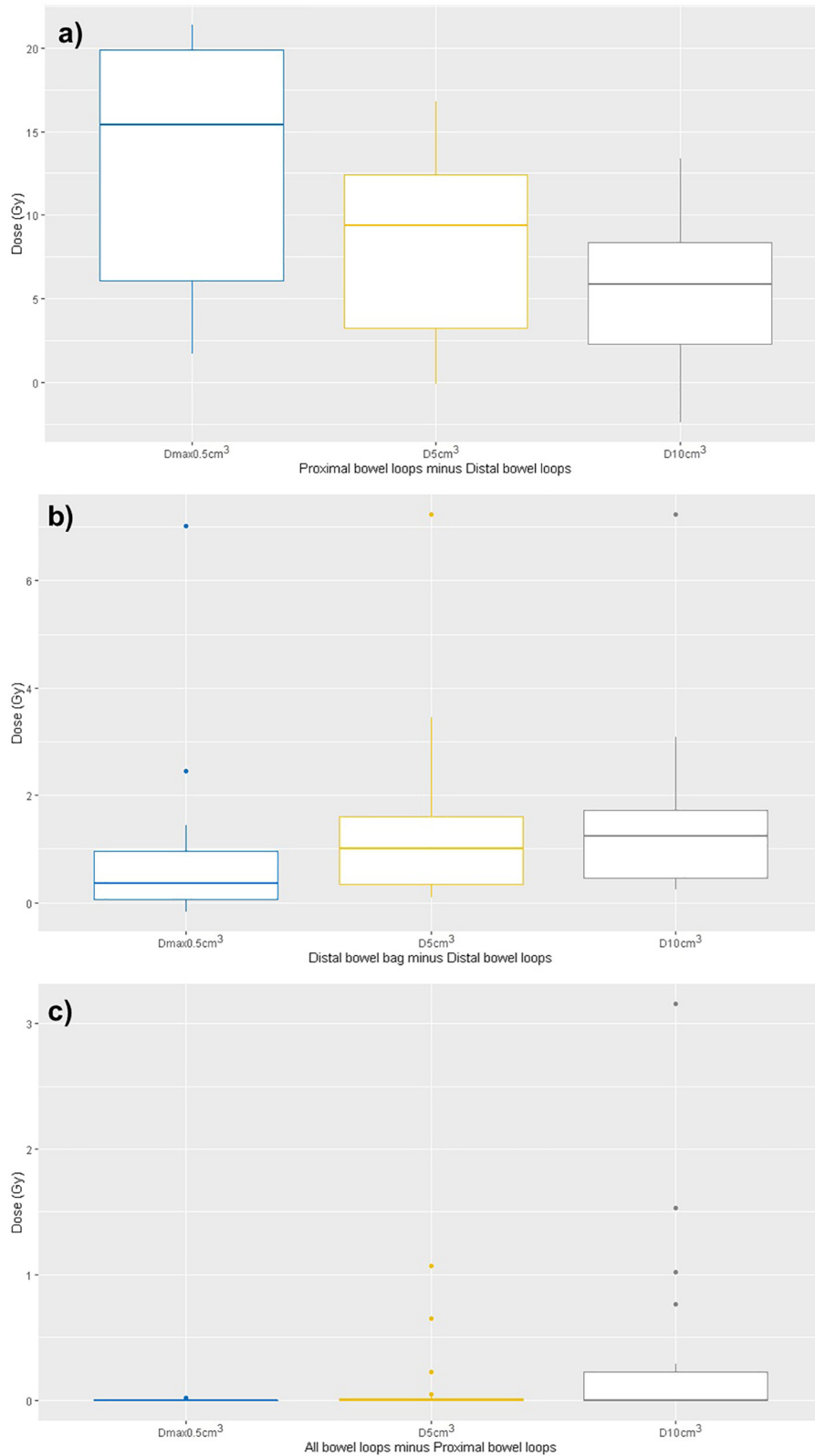
Fig. 2. a) Dose differences between Proximal bowel loops and Distal bowel loops, b) Dose differences between Distal bowel bag and Distal bowel loops and, c) Dose differences between All bowel loops and Proximal bowel loops.

As expected, doses to Distal_bowel_loops and Distal_bowel_bag were strongly correlated (Spearman's rho 0.84, 0.83 and 0.79 for Dmax0.5 cm^3, $D5cm^3$ and $D10cm^3$ respectively ($p < 0.001$ for all).

The median difference in Dmax0.5cm^3 to Distal_bowel_loops and Distal_bowel_bag was (Distal_bowel_bag minus Distal_bowel_loops) 0.4 Gy (range: −0.2 to +7.0), with the dose

Table 1
Dosimetric summary statistics.

Dose metric	Structure	Median dose (Gy)	Range (Gy)
$Dmax0.5cm^3$	Proximal bowel loops	25.5	11.7–34.0
	Distal bowel loops	10.2	4.6–15.7
	All bowel loops	25.5	11.7–34.0
	Distal bowel bag	11.4	8.3–15.7
$D5cm^3$	Proximal bowel loops	16.0	8.2–28.8
	Distal bowel loops	8.7	3.5–14.6
	All bowel loops	16.0	8.9–28.8
	Distal bowel bag	10.2	7.1–14.9
$D10cm^3$	Proximal bowel loops	12.1	6.5–24.3
	Distal bowel loops	7.8	3.0–14.1
	All bowel loops	12.1	7.6–24.3
	Distal bowel bag	9.4	6.5–14.6

to the Distal_bowel_bag being higher in 17/20 patients (Fig. 2b). Where the Distal_bowel_bag received a lower dose than Distal_bowel_loops, this was always < 0.2 Gy, likely reflecting small (real-world) inconsistencies in contouring and small differences in voxel assignment (inside or outside of structure edge) when creating intersecting/copied structures, which are clinically insignificant.

Similarly, the median difference in $D5cm^3$ to Distal_bowel_loops and Distal_bowel_bag was 1.0 Gy (range: +0.1 to +7.2), with dose to the Distal_bowel_bag being higher in all patients. In addition, the median difference in $D10cm^3$ to Distal_bowel_loops and Distal_bowel_bag was 1.2 Gy (range: +0.3 to +7.2), with dose to the Distal_bowel_bag being higher in all patients (Fig. 2b).

Where doses to the Distal_bowel_bag were higher than those for Distal_bowel_loops, this represents regions of bowel bag in relatively close proximity to the target, which did not contain bowel loops at the time of CT simulation.

Minimal differences were observed between the $Dmax0.5cm^3$, $D5cm^3$ and $D10cm^3$ to Proximal_bowel_loops and All_bowel_loops (median (and range) for All_bowel_loops minus Proximal_bowel_loops $Dmax0.5cm^3$, $D5cm^3$ and $D10cm^3$ respectively: 0 (0–0 Gy), 0 (0–1.1 Gy) and 0 (0–3.2 Gy) (Fig. 2c)).

Dosimetric summary statistics are provided in Table 1.

7. Discussion

This work has demonstrated that contouring individual bowel loops in close proximity to the target provides the relevant structures to limit high dose to individual bowel loops during planning that is based on commonly adopted SABR dose constraints (Fig. 1f and Fig. 3). Contouring the bowel bag only beyond this region does not result in any meaningful under-estimation of dose to bowel loops within this region (Fig. 1f). Doses to distal_bowel_loops

and distal_bowel_bag displayed strong monotonic positive correlations, further reassuring users of this technique that doses to the distal_bowel_bag are reflective of those received by the distal_bowel_loops. Having applied this technique locally, small bowel contouring times have reduced from around one hour to no more than 15 min. This approach therefore offers substantial time-saving implications.

The bowel bag has previously been identified as an alternative and faster method of bowel contouring [5] and one which allows for inter/intra-fraction changes in bowel position. The bowel bag contains both small and large bowel. It is acknowledged that bowel OAR constraints depend on the method used for bowel segmentation [6]. Individual bowel loop contouring has been shown to be superior to bowel bag in terms of predicting gastrointestinal toxicity [7] and this approach is favoured in situations where doses to small and large bowel are of importance [8], as is the case with abdomino-pelvic SABR. Contouring individual bowel loops, however, is time consuming. We have provided a time saving alternative, which provides the most relevant bowel loop dosimetric information without the need to contour all bowel across all CT slices. A restricted bowel loop contouring approach has also been used in the setting of online adaptive radiotherapy [9], a situation where contouring all individual bowel loops is impractical.

For this project both large and small bowel were combined into a single structure. The purpose of the project was to evaluate doses to any bowel proximal and distal to the target to ensure no relevant doses were being 'missed', rather than to analyse individual small vs. large bowel doses. That said, this process has now been adopted clinically, with the small and large bowel being separately contoured within the 3/2cm expansion around the PTV. Equally, one might opt to contour all bowel as one structure and apply the most conservative constraint to all bowel within the 3/2cm expansion, accepting that this may limit planning flexibility. At present, using the technique described here in clinical practice, the dose to the distal bowel bag is merely recorded (and ensured to be within the same constraints as applied for the proximal bowel loops), rather than used for optimisation. Going forward, however, it may be possible to use this structure within the optimisation process, thereby further limiting low dose spread. This would require separate evaluation.

This process can be used for abdomino-pelvic SABR using a conventional linac but is also relevant for MR-linac treatments, when rapid re-contouring for online adaptation is required [10]. The process may also be relevant for non-SABR targets (where the target does not include the whole pelvis) but this should be formally evaluated. Situations where mean bowel loop dose constraints are also used are likely to require contouring of the entire bowel structure, although the whole bowel bag could potentially be used as a time saving alternative. A 3/2cm expansion was used around the PTV in

Fig. 3. Axial and sagittal slice showing dose distribution in relation to the PTV 3/2cm expansion. Dark blue colourwash represents the 10 Gy isodose.

this project as visually this consistently contained all high and intermediate dose isodose and is in keeping with the approach for limited volume online adaptive planning [9]. For larger volume (lower dose) Dxcm^3 constraints, evaluating dose to bowel within a 3/2cm expansion alone could, in some cases, under-estimate the dose received by all bowel loops or distal bowel loops, thus it should be ensured that all relevant isodoses are contained within any selected PTV expansion and that doses to the distal bowel bag are always evaluated in conjunction with those to the proximal bowel loops. Similarly, for higher prescription doses or constraints, and where OAR maxima are being pushed to these limits, a larger expansion may be required.

8. Conclusions

Contouring individual bowel loops in close proximity to an abdomino-pelvic SABR target provides the relevant structures to limit high dose to individual bowel loops during planning when using commonly adopted SABR dose constraints. Contouring the bowel bag only beyond this region does not result in any meaningful under-estimation of dose to more distal bowel loops. This has substantial time saving implications.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

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