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A contouring strategy and reference atlases for the full abdominopelvic bowel bag on treatment planning and cone beam computed tomography images

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Title:

A contouring strategy and reference atlases for the full abdominopelvic bowel bag on treatment planning and cone beam computed tomography images

Short running title:

Contouring strategy for bowel bag

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All data generated and analyzed during this study are housed within a secure institutional database. Interested readers can contact the study authors with questions regarding access or reuse.

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None

Abstract

Purpose: To establish a practical contouring strategy with reference atlases for the abdominopelvic bowel bag on treatment planning computed tomography (TPCT) and cone beam computed tomography (CBCT) images.

Methods and Materials: A scoping literature review was done to evaluate the existing definitions and contouring guidelines for bowel bag and small bowel PRV-like structures. A comprehensive definition was proposed for the abdominopelvic bowel bag that expanded the RTOG Pelvic Normal Tissue Consensus definition. Seven patients, with TPCT and first-treatment-day CBCT images, were selected from our institutional database to represent a range of normal anatomy and CBCT image quality. TPCT and CBCT images were contoured using the proposed definition. During contouring, the RTOG definition's list of inclusion and exclusion structures was expanded. For areas with limited visibility of the bowel bag on either TPCT or CBCT, a set of operational definitions was developed based on consistently-visible reference structures.

Results: Our literature review showed that previously existing bowel bag definitions predominantly focus on the pelvic region, and do not provide a complete and practical description of the full abdominopelvic contour relative to structures consistently visible in all radiotherapy images. Our proposed contouring strategy has four components: a definition, a list of inclusion and exclusion structures, fifteen tabulated operational definitions, and a set of atlases. We define the bowel bag as the peritoneal cavity and retro-peritoneal duodenum and ascending and descending colon, as visualized at the time of image acquisition. The operational definitions formalize the location of the peritoneal fascial planes through a simple look-up table. The atlases are available as a supplemental electronic resource. The proposed contouring strategy and reference atlases were successfully used on both TPCT and CBCT images.

Conclusions: This study produced a practical contouring strategy and reference atlases to enable reproducible delineation of the full bowel bag on TPCT and CBCT images. The strategy is a necessary first step towards consensus contouring with reduced observer variability, which is a pre-requisite for evaluation of cumulative dose and its correlation with toxicities, adaptive planning strategies, and automated contouring potential.

Introduction

The small and large bowel span the peritoneal and retroperitoneal abdominal and pelvic regions. They are large, mobile[1] structures and are dose-limiting organs for many radiotherapy regimens due to the risks of acute and long-term toxicities.[2–4] There are two main approaches to contouring a bowel Planning-at-Risk Volume (PRV) on Treatment Planning Computed Tomography (TPCT) images: the bowel bag and the individual bowel loops. The bowel bag can be described, conceptually, as all abdominal and pelvic regions that potentially contain small and large bowel. Radiation Therapy Oncology Group (RTOG) consensus contouring guidelines exist for normal anatomy in the pelvis[5] and upper abdomen.[6] The bowel bag approach is most commonly applied in the pelvis, while abdominal strategies and guidelines favor the loops approach. This resulted in a relative deficit in guidance for contouring the bowel bag in the upper abdomen.

The small bowel spans the pelvis and upper abdomen and has been shown as particularly mobile.[1] Studies have observed daily gross positional shifts of small bowel loops of up to 4 cm.[7,8] Margins of up to 3 cm on individual loops were recommended to account for movement seen in 90% of patients.[7,8] Assessment of the location of the small bowel during treatment could improve the accuracy of estimating the cumulative bowel dose and its correlation with toxicities. However, the quality of the cone beam computed tomography (CBCT) images that are used for image guidance at the time of treatment is usually insufficient for contouring the individual loops manually.[9] The bowel bag has inherently lower specificity than individual loops. However, it may be better suited to account for mobile anatomy. Tuomikoski et al.[9] indicated that on-treatment CBCT image quality might be sufficient for bowel bag contouring in the pelvis. The points above collectively support the need for the development of complete bowel bag contouring strategies for the upper abdomen and the pelvis that are suitable for use on both TPCT and CBCT images.

This study first summarizes existing bowel bag definitions and contouring guidelines from the literature. A new, comprehensive definition is then proposed and applied to contour a sample set of images. The new contouring strategy accompanied with reference atlases, aims to accomplish three goals: (1) extend the existing contouring instructions for the pelvic bowel bag into the upper abdomen; (2) enable bowel bag contouring on both TPCT and CBCT images; and, (3) improve contouring reproducibly to enable future development of useful ground truth and consensus contours. These goals are a pre-requisite for evaluation of cumulative dose and its correlation with toxicities, adaptive planning strategies, and automated contouring potential.

Methods and Materials

1. Literature review

A scoping literature review (PRISMA-ScR[10]) was performed to identify unique small bowel and bowel structure definitions using a bowel bag approach. PubMed, Web of Science, and major radiation oncology journals were searched independently by two authors (XX and XX) for the date range from January 1st, 2000 to January 1st, 2022 to identify primary articles. The following predefined generic and Medical Subject Heading (MeSH) search terms used were: small bowel, bowel, bowel bag, intestinal cavity, intestine, peritoneal cavity + bowel, and, peritoneal space + bowel. Database searches also included 'AND (radiation therapy OR radiotherapy)'. Some mention of the bowel structure in the abstract was used as the criteria for reviewing the full article. Only English language articles were reviewed. Unique definitions and guidelines were then summarized and compared.

2. Patient image selection

Our institutional database was queried for patients with thoraco-lumbar, lumbar, lumbo-sacral spinal metastases, treated between January and July 2016 with available first-day CBCT images of the abdominal-pelvic region. TPCT and CBCT images for these patients were manually reviewed and seven patients were selected. The selected patients were six male and one female (rationale below). The mean time between acquisition of TPCT and CBCT scans was 2 weeks. All selected patients had been scanned and treated in the supine position without oral contrast and using 3 mm scan slice thickness. Four dimensional CT scans were not used. The selected patients met the following criteria: (1) the patients represented a range of normal anatomy – e.g., obese vs. cachectic, different levels of GI/GU structure fullness; (2) their TPCT images covered the full abdominal-pelvic region; (3) their CBCT images represented the clinically observed range of abdominal-pelvic image quality; (4) their CBCT images used the largest clinically-available Field of View (FOV, Elekta XVI M20: 26.0 cm axially, 41.0 cm diameter); and, (5) their CBCT images had sufficient lateral anatomical coverage such that the abdominal wall was not truncated.

3. Development of a new contouring strategy

A new bowel bag definition was proposed based on the literature review. The inclusion and exclusion structures from the RTOG Pelvic Normal Tissue Contouring guidelines[5] were modified and expanded. Operational definitions were developed to maximize contouring reproducibility by clearly identifying boundary location relative to specific and visible anatomy. Contouring on TPCT and CBCT images was performed on each transverse image slice, starting inferiorly. Contours were performed by a single board-certified radiation oncologist; the Chair of our institution's GI radiotherapy site group who has

>10 years of experience practicing in all GI anatomic sub-sites. TPCT and CBCT images were assessed for consistent visibility of inclusion, exclusion, bounding, and reference structures.

During the development of the contouring strategy, areas with limited visibility of known anatomical boundaries were identified in some locations in TPCT images, and more broadly in CBCT images - an example for fascial planes is shown in figure 1. To address this, a number of human sectional anatomy references (e.g. Ellis, Logan and Dixon, 1999[11]) were used to develop informed estimates of bowel bag boundary locations, then Operational Definitions (ODs) were developed to reproducibly dictate the bowel bag boundary locations relative to reference structures in the areas with limited visibility. ODs indicate how to join easily-identifiable points on reference structures that span the region of ambiguity with one of three line choice: straight, lateral or minimum distance (figure 2). The specific type of line connection between cardinal points on the reference structures was chosen to maximize reproducibility while maintaining a level of accuracy deemed clinically appropriate for all anatomies. The boundary locations dictated by the ODs are conservative; opting to include more volume rather than less.

Images from three of the seven patients were used for the atlases as follows. The main atlas patient is a male whose CBCT is of good quality and with a FOV that fully covers the inferior boundary of the bowel bag. The planes/slices from this patient make up the main atlas. Given that the CBCT FOV is limited axially to 26.0 cm, a second male patient whose CBCT FOV is centered superiorly (includes diaphragm and beyond) was used to supplement the main atlas patient by providing TPCT and CBCT atlas coverage of the upper abdomen section. A third patient (a female) was used to cover gender-specific pelvic anatomy (mid-femoral heads to iliac crests). The three atlases include the contoured and the non-contoured images for both TPCT and CBCT for each selected slice. Transverse slices spanning the inferior/superior-most contoured bowel bag are included in the atlases, along with three coronal and five sagittal planes. The full atlases are included as supplementary materials. Literature review results, contouring strategy development work, images and atlases were all reviewed by gastrointestinal radiation oncologists from three outside institutions to ensure face validity of the work and to gather any feedback to incorporate on the strategy's recommendations.

Results

1. Summary of literature review

Thirty five articles were found containing relevant structure definitions, fourteen of which were unique.[1,2,5,8,9,12–20] The earliest reference containing each unique definition is summarized in table 1. The rest of this section presents our key observations from the literature review.

The majority of the definitions in the literature are in the context of developing a PRV structure for pelvic target volume radiotherapy planning. Overall, bowel structures in the literature are described either conceptually or anatomically. The conceptual definitions use the space potentially occupied by the small ± large bowel, at any time during the treatment or at the time of imaging. The anatomical definitions use the content of the peritoneal/intestinal/abdominal cavity/space. Roeske et al.[17] specifically indicated, and demonstrated in their figure 3, a volume smaller than the peritoneal space. Gunnlaugsson et al.[12] described a volume larger than the peritoneal space by explicitly including abdominal fat. Some definitions explicitly list inclusion and exclusion structures. Other definitions provide a boundary location relative to a specific aspect of an exclusion structure. The number of bounding structures listed is highly variable and the structures provided typically depend on the treatment and/or disease site. Banerjee et al.[13] provided the most complete list in the pelvic region. Gunnlaugsson et al.[12] explicitly referenced abdominal organs that extend above the pelvis. The rest of the literature referenced only pelvic structures or used generalizations – e.g. Gay et al.[5] excluded muscles, bones and non-GI structures. Some definitions are accompanied by a figure – e.g., Banerjee et al.[13] and Gay et al. (RTOG Pelvic guidelines)[5] gave figures and atlases confined to the pelvic region below the iliac crests. Banerjee et al.[13] and Jhingran et al.[21] are the only two studies that included a temporal aspect in the definition by stating that their definitions apply to the potential bowel location at any time during treatment. Gay et al. (RTOG Pelvic guidelines)[5] provided a thorough description of the inferior boundary location relative to the patient anatomy. All descriptions of the superior boundary are relative to radiotherapy pelvic target volume or treatment field edge, not patient anatomy. Tuomikoski et al.[9] is the only study that applied their definition to CBCT images, confined to the pelvic region. None of the definitions specifically addressed the location or shape of the boundary in areas with limited contrast.

The RTOG Normal Tissue Pelvis Consensus guidelines and atlases[5] may be sufficient for reproducible contouring of the bowel bag in the pelvic region on TPCT images. However, they can benefit from additional guidance, particularly with the various definitions that exist in the literature. Additional guidance is needed for bowel bag contouring in the upper abdominal region on both TPCT and CBCT images, and in the pelvic region on CBCT images.

2. Summary of the proposed contouring strategy

Our proposed strategy has four components: a definition, a list of inclusion and exclusion structures, fifteen tabulated operational definitions, and a set of atlases. The following subsections summarizes each of those components.

2.1. Bowel bag definition

We propose defining the bowel bag as the space potentially occupied by small and large bowel loops at the time of image acquisition. Our definition means that the bowel bag includes the peritoneal cavity plus the partially retro-peritoneal duodenum and ascending and descending colon. In our definition, the RTOG Pelvis Consensus description of the inferior boundary is used (the most inferior small or large bowel loop or above the rectum or anorectum, whichever is most inferior). To remain consistent, the superior boundary is defined as the most superior small or large bowel loop, or below the diaphragm. The peritoneal fascial plane therefore represents the majority of the radial boundary. In the relevant axial range, the radial boundary is extended to include the duodenum and ascending/descending colon. The radial boundaries are modified to exclude non-gastrointestinal structures within the peritoneal cavity (liver, gallbladder and spleen) which is consistent with the RTOG Pelvis Consensus definition that excludes other pelvic organs.

2.2. Inclusion and exclusion structures

The following is the full list of inclusion and exclusion structures. Structures to be included are: all small and large bowel loops and the peritoneal space, along with the mesorectal fat and rectum if they are co-located axially in slices with the inferior-most loops of bowel. Structures to be excluded are: muscles (e.g., rectus abdominus, transverse abdominus, obliques, psoas, obturator internus, quadratus lumborum), bones, vessels (e.g., external iliacs, internal iliacs, common iliacs, obturator vessels, aorta, IVC, superior mesenteric vessels, renal vessels), bladder, prostate, seminal vesicles, rectum (if not co-located with inferior-most bowel loops), kidneys, liver, spleen, pancreas, stomach, adrenal glands, mesorectal fascia, inguinal ligament, retro-peritoneal fascia, retro-peritoneal fat, peri-renal fascia, and peri-renal fat.

2.3. Operation Definitions (ODs)

Fifteen unique ODs are proposed in a simple look-up table (table 2). The ODs are concentrated in the high pelvis and abdominal regions and mainly define the posterior and posterior-lateral boundaries. The table offers a standardized sentence format as follows. *If the peritoneal fascial plane is not visible in the* *direction* relative to the *origin structure*, then draw a *line type* from the *X-most aspect* of the origin structure to the *Y-most aspect* of the *terminal structure* to contribute to the *bowel bag boundary* of the *bowel bag*. Examples of the use of ODs are shown in figure 3. ODs should be ranked as lowest in priority relative to all other components of the strategy – examples are shown in figure 4.

2.4. Atlases

A summary of atlas coverage is shown in the supplementary materials. The three atlases are provided as an electronic supplement. The atlases contain coronal and sagittal slices that show the axial extent of the bowel bag and shows the position of each axial slice in the atlas relative to the gross anatomy. The axial slices are shown for the co-registered TPCT and CBCT images with and without contours to avoid the contours masking faint relevant anatomy features such as the fascial planes. Each OD is highlighted with text in the atlases.

Discussion

1. Practical use of the proposed contouring strategy

Our new definition of the bowel bag differs from previously published definitions in the following respects: (1) It avoids referencing the abdominal cavity, whose physical interpretation may vary. (2) It explicitly addresses sections of bowel that fall in the retro-peritoneal space. (3) It describes all boundaries, including the inferior and superior boundaries, strictly relative to normal tissue anatomical structures without referencing radiotherapy targets or dose distribution. (4) It provides a specific point in time at which the definition should be applied, eliminating the need to infer the potential mobility of structures at boundaries.

Although the strategy covers the full bowel bag, it can be applied to any subsection. The wording of the bowel bag definition differs slightly from the RTOG Pelvic Normal Tissue Consensus atlases in two respects to improve clarity and consistency: (1) The proposed strategy uses the peritoneal cavity to describe the physical extent of potential small and large bowel loop position instead of the abdominal contents. (2) The proposed strategy explicitly state that they should be applied to the structure location at the time of image acquisition.

The following sequence should be used by an observer wishing to use the proposed contouring strategy: (1) Begin by deciding the axial range of interest. (2) Review the bowel bag definition to determine if your axial range of interest spans the inferior-most and/or superior-most limits of the bowel bag and, if required, apply the description of these locations from the definition to find the first/last slices of interest in your scan. (3) Review the list of inclusion and exclusion structures. (4) Begin contouring the peritoneal space inferiorly. (5) Whenever the peritoneal and/or renal fascial planes are not visible, determine the relevant origin structures from the ODs in table 2 (first row is inferior-most and last row is superior-most). The last column in table 2 refers to atlas slices that provide a visual example of the relevant ODs. (6) If implementing an operational definition from table 2 causes exclusion of a visible inclusion structure, or inclusion of a visible exclusion structure, then modify your contour to wrap around the visible extent of that structure, using atlas examples.

In the ODs, the straight-line approach demonstrates a clear preference for reproducibility over exact anatomical accuracy – an example is shown in Figure 6a of the supplementary materials. In the abdominal region, straight lines seem to approximate true anatomical location better as they are not straight lateral unless spanning only a small distance. The choice of the cardinal aspects of the reference structures is made based on the range of normal anatomy observed. For instance, as shown in figure 6b of the supplementary materials the visible retro-peritoneal planes in the upper pelvis were typically found farther posterior along the psoas muscle in cachectic patients versus extending off the anterior aspect in the normal-obese patients. For this reason, in OD#1 the lateral-most aspect of the psoas muscle was used as the average between these two extremes. Similarly for kidney-based ODs (OD#2 to 7), the anterior-most aspect of the kidney was used as the straight-line connection point because the thickness of pararenal fat is variable.

2. CBCT structure visibility

The visibility of anatomical structures varies between and within CBCT images. Noise affects the visibility for larger patients (figure 6c of supplementary materials). Cachectic patients have limited intra-abdominal/intra-peritoneal fat and space, which limits the contrast between individual organs (figure 6d of supplementary materials). Mobile gas causes artifacts that obstruct visibility locally (figure 6e of supplementary materials). However, contour interpolation from adjacent slices can mitigate the effect of artifacts. Gas artifacts can be useful in differentiating (but not delineating) bowel loops (small gas bubbles) from stomach (large gastric bubble). When visible, small gas artifacts are useful in detecting the superior-most or inferior-most bowel loops. The pancreas is referenced by ODs but it is not consistently visible in CBCT images. However, minimal bowel bag volume changes were observed when OD#7 (stomach-kidney) was used instead of the stomach-pancreas-kidney combination (OD#15 & OD#6) - figure 6f of supplementary materials. Overall, our review of clinical CBCT images supports Tuomikowski's[9] conclusion that the visualization of small bowel loops on CBCT images is variable and insufficiently consistent for contouring, while the majority of the bowel bag boundary can be consistently identified for contouring on CBCT images.

3. Limitations of the contouring strategy

There are some areas that present contouring challenges. In the low pelvis, the anterior-lateral pocket contiguous with the anterior abdominal wall (lateral termini of rectus abdominus) can be delineated by estimating the location of the inguinal ligament; the ligament is often difficult to see even on diagnostic imaging. The locations of the junction between the mesorectum and sigmoid, and the junction between the duodenum and stomach are difficult to identify despite detailed descriptions in the RTOG Pelvic and Upper Abdominal Normal Tissue guidelines, respectively. Exclusion of some pelvic organs on CBCT images can prove challenging, as can the exclusion of the mesenteric vessels in the pedicle region. Patients that have had viscera removed surgically will also have altered anatomy that can complicate the application of the strategy. Tests using our patient scans with mock hepatectomies and pancreatectomies have shown the ODs to be robust to alterations of this sort, but undoubtedly as the strategy is used more there will be circumstances that highlight the need to modify the ODs.

4. Future direction

The proposed contouring strategy forms the basis for our forthcoming study on inter- and intra-observer variability on contouring the bowel bag on TPCT and CBCT images, which has never been reported previously. Consensus contours from multiple expert observers with small observer variability is the basis for evaluating the cumulative dose to the bowel bag and its correlation with toxicities, for evaluating adaptive planning strategies, and for assessment of automated contouring potential. Importantly, this strategy for contouring can work in conjunction with existing maximum point dose constraints commonly used in stereotactic ablative body radiotherapy (SABR). Understanding the impact of low-dose splash areas on acute and long-term toxicities for abdominopelvic SABR is an important relative knowledge gap in the growing field of curative- and palliative-intent SABR. The common use of 4D- or slow CTs for upper abdominal radiotherapy also makes delineating individual loops of bowel difficult and supports the use of a strategy anchored in reliably visible reference structures such as those defined in our strategy.

Conclusions

This study produced a practical contouring strategy and reference atlases for more reproducible contouring of the full bowel bag on TPCT and CBCT images. The main novel aspects are the inclusion of the upper abdomen in addition to the pelvis, consideration for CBCT images, and the use of ODs to approximate contours in areas of limited visibility. There are four components to the strategy: a definition, a list of inclusion and exclusion structures, ODs, and a set of atlases. The atlases are provided as a supplemental electronic resource.

Declaration of interests

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.

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Table and figure captions

Table 1: Summary of structures defined using a bowel bag approach. For RTOG trial protocols, the number of patients is the expected accrual. RTOG = Radiotherapy Oncology Group, pts = patients, GYNE = gynecological, GU = genitourinary.

Reference	Disease site, # pts	Bowel naming	Definition
Muren *et al*. 2001[16]	Bladder, N = 25	Small intestine	Volume potentially containing small intestinal tissue.
Roeske *et al*. 2003[17]	GYNE, N = 50	Small Bowel, SB	Volume bounded by outermost extent of contrast-enhanced small bowel loops on all slices below the L4-5 interspace, explicitly excluding small bowel in upper abdomen.
Cavey *et al.* 2005[18]	Prostate, N = 8	Intestinal cavity	Conceptually described as contents of the intestinal cavity, bounded anteriorly and anterolaterally by the abdominal wall, posterolaterally by retroperitoneal and deep pelvic muscles and posteriorly by great vessels, vertebral bodies, sacrum and rectum. Cranio-caudally, from top of iliac bones to most inferior slice with fat anterior to bladder. Rectum excluded.
Pollack et al. 2006[19]	Prostate, N = 100	Bowel	Region of potential small bowel and distal colon and/or sigmoid.
Price et al. 2006[20]	Prostate, N = 10	Bowel	Conceptually described as including all space potentially occupied by bowel, i.e. region between pelvic nodal areas from the sigmoid flexure, just above the rectum inferiorly, to 1 slice above most superior (periprostatic, peri-seminal vesicle, external iliac, proximal obturator, and proximal internal iliac, presacral/perirectal) lymph nodes.
Gunnlaugsson *et al*. 2007[12]	Rectum, N = 28 18 M/10 F	Whole Abdomen	Entire abdominal contents, explicitly including small bowel, large bowel, mesenteric structures, and abdominal fat and excluding liver, kidneys, spleen, large vessels, and psoas muscles.
Sanguineti *et al*. 2008[1]	Prostate, N = 9	Intestinal cavity, IC	Conceptually described as the container, versus the content, acknowledging bowel loops are physically confined within the intestinal cavity, IC. IC is bounded anteriorly by the abdominal/pelvic anterior wall, laterally by the pelvic wall and inferiorly by the rectum and/or bladder.
Fiorino *et al*. 2009a[2]	Prostate, N = 175	Intestinal cavity, IC	IC by Sanguineti *et al*. 2008 but excluding 5- to 7-mm margin around PTV. Whole Intestinal Cavity, WIC = IC Sanguineti *et al*. 2008, N = 20
Tuomikoski *et al*. 2011[9]	Bladder, N = 5	Intestinal cavity, IC	Conceptually described as abdominal cavity volume, limited anteriorly and laterally by the abdominal/pelvic wall and inferiorly by the rectum/bladder; explicitly including all visible bowel loops.

Hysing *et al*. 2011[8]	Prostate, N = 3	Intestinal cavity, IC	Conceptually described as least specific PRV for small bowel, the physical boundary, the intestinal cavity. Volume from the slice above L5, superiorly, to the slice where pubic bones meet, inferiorly. Bounded anteriorly and laterally by abdominal/pelvic wall and posteriorly by deep muscles of back/pelvic bones.
Gay *et al*. 2012[5]	GU/GYN, N = 2, 1 M/1 F	Bowel NOS BowelBag	Bowel NOS (non-GI definition): peritoneal space occupied or potentially occupied by large or small bowel BowelBag: abdominal contents, excluding muscle, bone, and all overlapping non-GI structures. Inferiorly bounded by most inferior of: inferior-most small or large bowel loop, or superior limit of rectum or ano-rectum. Rectum and ano-rectum in the same slice as, or superior to, the inferior-most small or large bowel loop should be included. Superiorly, the volume is extended 1 - 5 cm superior of PTV.
Banerjee *et al*. 2013[13]	Rectum, N = 67, 38 M/29 F	Peritoneal space, PS	Conceptually described as the area where small or large bowel may lie at any point during treatment. Volume bounded anteriorly and laterally by posterior aspect of abdominal muscles, posteriorly by vertebral bodies, sacrum, or posterior aspect of peritonealized sigmoid colon. Inferiorly boundary 1 slice below inferior-most small bowel loop and superior boundary 5 slices superior of the treatment plan field edge. All contoured small and large bowel explicitly included and bladder, prostate, ovaries, and uterus excluded.
Pollack *et al*. 2015 RTOG 0534[14]	Prostate, N = 1764	potential bowel space	Conceptually described as the small and large bowel's potential space within the pelvis, including regions, laterally, on either side of bladder to medial edge of lymph node outline. Bounded inferiorly by top of prostate bed and superiorly by superior-most slice of nodal CTV. Pre-sacral lymph node region explicitly excluded.
Jhingran *et al*. 2015 RTOG 0418[21]	GYNE N = 92	Small bowel	Conceptually described as the area where bowel may lie at any point during treatment. Volume bounded by edge of the peritoneum, surrounding all small bowel loops and defined to a minimum of 2 cm superior of PTV.

Table 2: List of Operational Definitions (ODs). The color coding is based on the origin structure. Atlas slice index references: MM = Main Male, UA = Upper Abdominal, PF = Pelvic Female, p# = page number in the atlas.

OD#	Direction	Origin structure	X-most aspect of origin structure	Line type	Terminal structure	Y-most aspect of terminal structure	Bowel bag boundary	TPCT Slice ref. #	CBCT Slice ref. #
1	lateral	psoas major	lateral-most	lateral	transverse abdominis or obliques or iliacus or quadratus lumborum	N/A	POST	MM-p26 PF-p113 PF-p115	PF-p113 PF-p115
2	lateral	kidney	anterior-most	lateral	transverse abdominis or obliques or iliacus or quadratus lumborum	N/A	POST	MM-p36 UA-p68	MM-p36 UA-p68
3	medial	kidney	anterior-most	straight	central vessels or aorta or IVC	lateral-most	POST	MM-p35 UA-p69	MM-p35 UA-p69
4	lateral (R)	kidney	anterior-most	lateral	liver	N/A	POST	MM-p40 UA-p73	UA-p73
5	lateral (L)	kidney	anterior-most	straight	spleen	anterior-most	POST	MM-p43 UA-p76	UA-p76
6	medial (L)	kidney	anterior-most	straight	pancreas	lateral-most	POST	MM-p47 UA-p75	
7	medial (L)	kidney	anterior-most	straight	stomach	lateral-most	POST	MM-p48	
8	medial	liver	posterior medial-most	straight	central vessels or IVC	lateral-most	POST	MM-p45	UA-p77
9	lateral (R)	liver	anterior-most	lateral	transverse abdominis	N/A	POST/LAT	MM-p41	

10	anterior	liver	anterior-most	minimum distance	rectus abdominis	N/A	ANT/LAT	MM-p51 UA-p84	UA-p84
11	lateral	spleen	anterior-most	lateral	transverse abdominis or obliques	N/A	POST	MM-p46 UA-p83	UA-p83
12	medial	spleen	anterior-most	straight	pancreas	lateral-most	POST	MM-p50 UA-p79	UA-p79
13	medial	spleen	anterior-most	straight	stomach	lateral-most	POST	MM-p52	UA-p81
14	anterior	stomach	anterior-most	straight	liver	left lateral-most	ANT	MM-p54	
15	lateral (L)	stomach	lateral-most	straight	pancreas	left lateral-most	POST	MM-p49 UA-p80	UA-p80

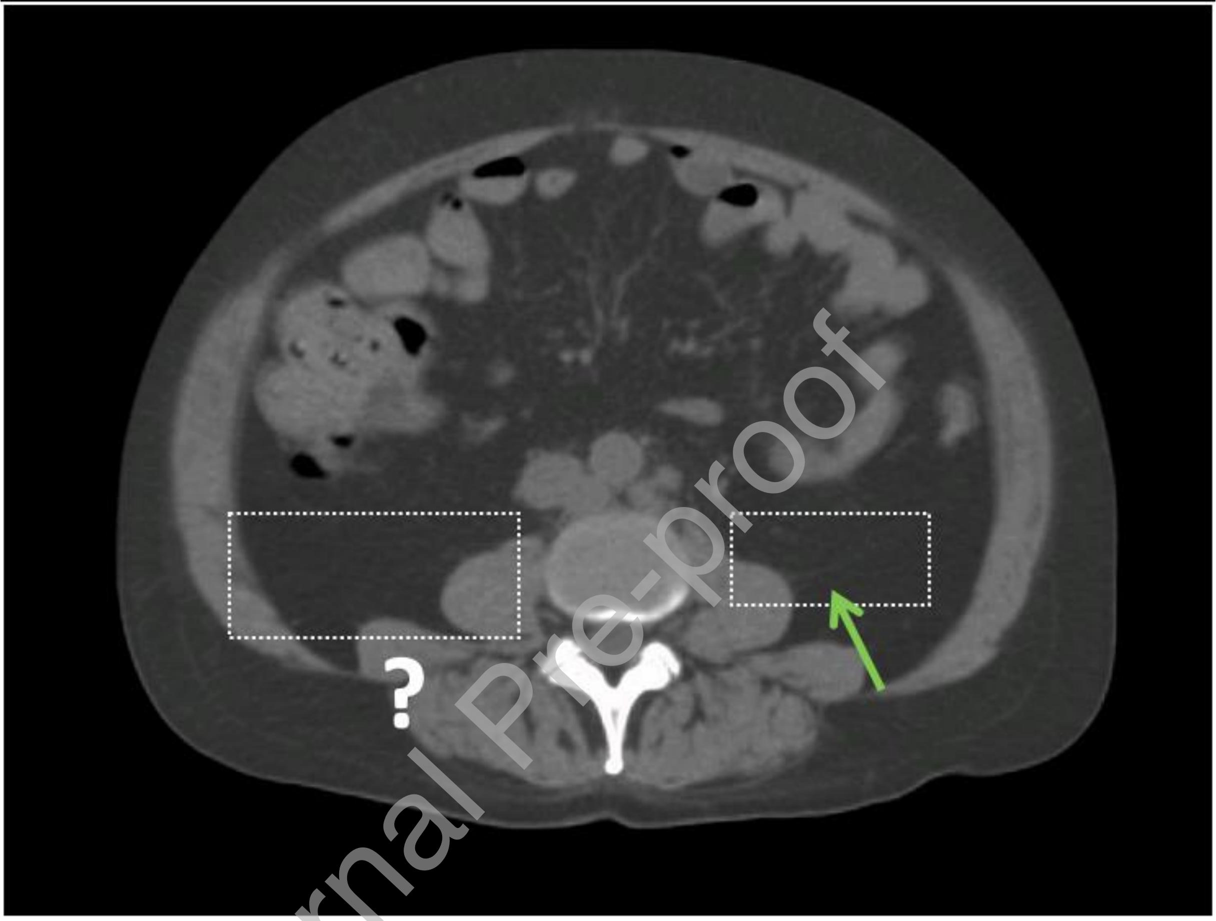

Figure 1: An example of limited visibility that lead to the development of Operational Definitions (ODs) in this study. The green arrow on patient left shows a faintly visible peritoneal fascial plane which defines the bowel bag boundary. On patient right the fascial plan is not visible, which requires the use of an OD.

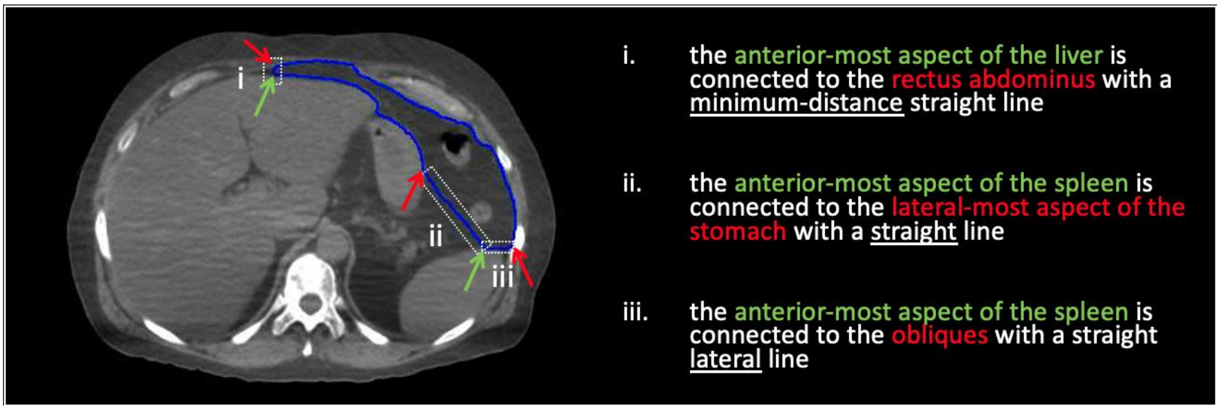

Figure 2: The three line types used to approximate the bowel bag boundary location.

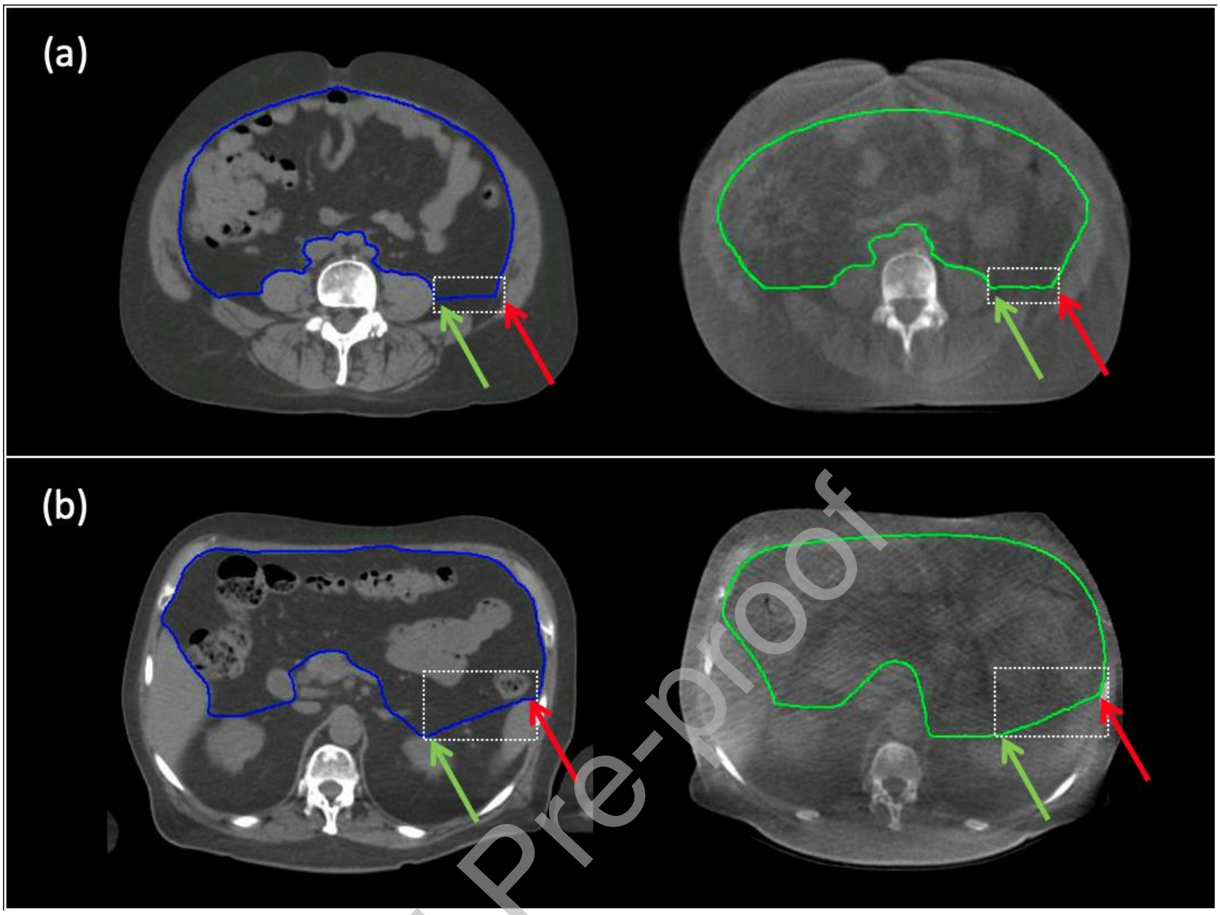

Figure 3: Examples of operational definitions (ODs) on TPCT (left) and CBCT (right) within the dashed white boxes. (a) OD#1: if the peritoneal fascial plane is not visible in the lateral direction relative to the psoas major, then draw a lateral line from the lateral-most aspect of the psoas major to intersect the iliacus and contribute to the posterior boundary of the bowel bag. (b) OD#5: if the peritoneal fascial plane is not visible in the left lateral direction relative to the kidney, then draw a straight line from the anterior-most aspect of the kidney to the anterior-most aspect of the spleen to contribute to the posterior boundary of the bowel bag. Green and red arrows indicate, respectively, the relevant aspects of the origin and terminal structures.

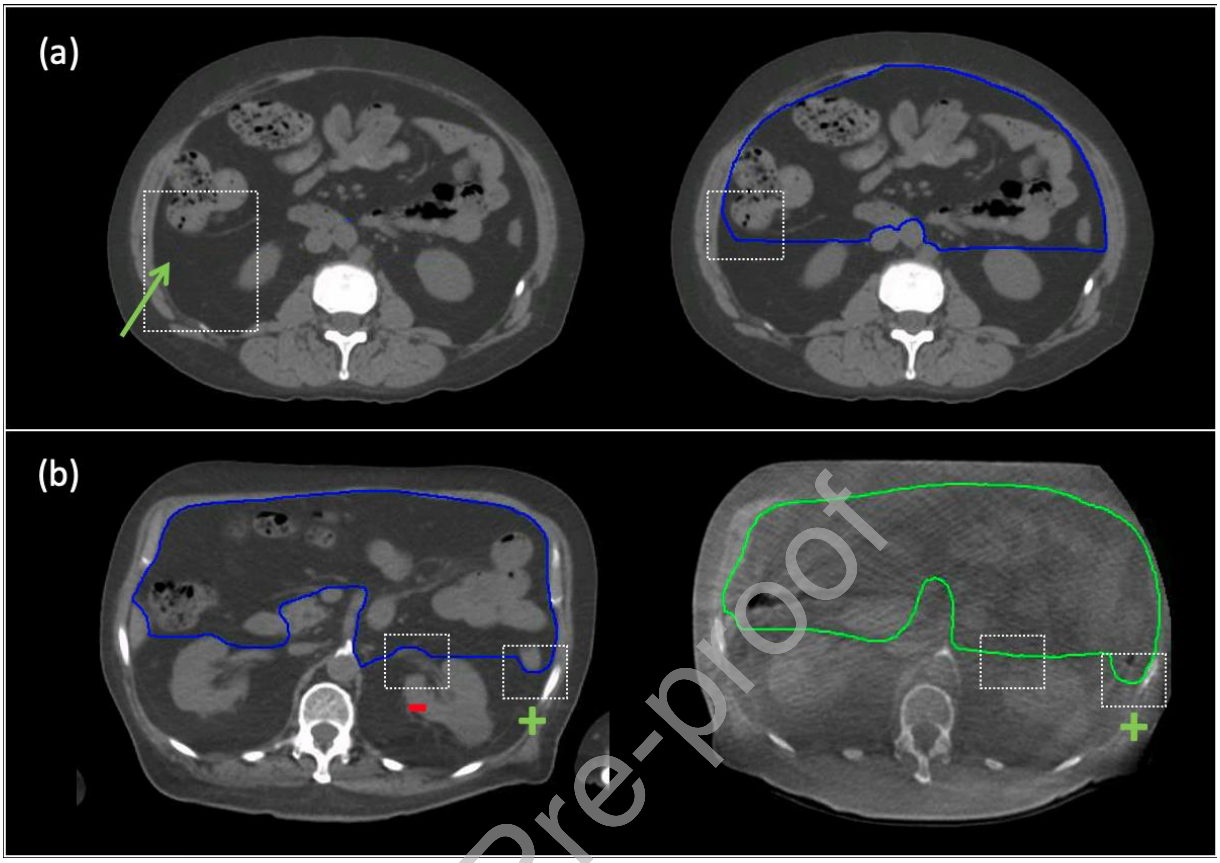

Figure 4: Two examples of the hierarchy in the application of the contouring strategy within the dashed white boxes. In example (a), the left panel shows the partially-visible fascial plane on TPCT that overrides OD#2. The application of this hierarchy is shown in the right panel of (a). In example (b), the left panel shows that the inclusion of the bowel loop (denoted by a green +) out-ranks OD#2, and the exclusion of the hepatic vessels (denoted by a red -) out-ranks OD#3. For the corresponding CBCT slice in the right panel of (b), there is insufficient CBCT contrast for the exclusion of the hepatic vessels.