Evaluation of Small Bowel Motion and Feasibility of using the Peritoneal Space to Replace Bowel Loops for Dose Constraints during Intensity-Modulated Radiotherapy for Rectal Cancer

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Research

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Abstract

Background

The goal of this study was to assess small bowel motion and explore the feasibility of using peritoneal space (PS) to replace bowel loops (BL) via the dose constraint method to spare the small bowel during intensity-modulated radiotherapy (IMRT) for rectal cancer.

Methods

A total of 24 patients with rectal cancer who underwent adjuvant radiotherapy were selected. Weekly repeat CT scans from pre-treatment to the fourth week of treatment were acquired and defined as Plan, 1W, 2W, 3W, and 4W. BL and PS contours were delineated in all of the scans. Two IMRT plans called P_{PS} and P_{BL} were designed on Plan CT using two dose PS and BL constraint methods, respectively, and then copied to CT 1 ~ 4W. The shift%, dose volume, and NTCP of the small bowel in P_{PS} and P_{BL} during treatment were evaluated.

Results

Overall, 109 sets of CT scans from 24 patients were acquired, and 218 plans were designed and copied. The PS and BL volumes were 1339.28 cc and 250.27 cc. The BL and PS shift% V_{15} was 28.48% and 11.79% ($p = 0.000$), which was less in the prone position than in the supine position (25.24% vs 32.10%, $p = 0.000$; 9.9% vs 14.85%, $p = 0.000$). On all of the CT scans, most P_{PS} small bowel dose volumes were less than from P_{BL}. V_{15} was 170.07 cc vs 178.58 cc ($p = 0.000$), and they had a significant correlation. The NTCP of chronic and acute side effects from P_{PS} was significantly less than P_{BL} (2.80% vs 3.00%, $p = 0.018$; 57.32% vs 58.64%, $p = 0.000$).

Conclusions

This study indicated that small bowel motion may lead to uncertainties in its dose volume and NTCP evaluation during IMRT for rectal cancer. The BL movements were significantly greater than PS, and the prone position was significantly less than the supine position. Using PS instead of BL can spare the small bowel. $V_{15} < 830$ cc is the dose constraint standard.

Background

Adjuvant radiochemotherapy is a widely accepted treatment mode in patients with locally advanced rectal cancer. It can result in a significant reduction in the local recurrence rate by up to 30% and improve the 5-year disease-free survival rate [1–6].

Although radiochemotherapy can help cure many rectal cancer survivors, acute and chronic intestinal side effects (12%-50%) such as diarrhoea, faecal incontinence, and late small bowel obstructions have attracted increasing attention because they may affect patients' quality of life and even interrupt treatment [7–10]. Studies have shown that the irradiated small bowel volume is closely related to toxicity caused by radiotherapy, so reducing its irradiated volume is the key approach to effectively prevent and reduce toxicity [11, 12]. Although intensity-modulated radiation therapy (IMRT) reduces the risk of radiation-induced toxicity, toxicity remains a significant concern.

In 2010, the Quantitative Analysis of Normal Tissue Effects in the Clinic (QUANTEC) review provided the available dose volume data for small bowel toxicity. Acute small bowel injury has been described with a threshold dose of grade 3 or greater toxicity when 120 cc volume of individually contoured bowel loops (BLs) receive ≥ 15 Gy or when 195 cc of the contoured peritoneal space (PS) receives ≥ 45 Gy [13–14]. These are commonly incorporated into radiotherapy protocols in clinical practise.

Contouring the PS and BL are two primary ways to evaluate the small bowel dose volume [15–16]. However, the small bowel is always in motion and there may be uncertainties in dose volume evaluations. The characteristics of narrow high dose distribution in IMRT technology will further increase this uncertainty.

PS contouring has the advantages of accuracy, convenience, and repeatability compared with BL contouring. This volume can allow the small bowel to lie at any point during treatment and can mitigate the impact of small bowel movements. The scope of this study was to quantify the impact of small bowel movements on the dose volume and normal tissue complication probability (NTCP) estimates and feasibility of using PS replace BL for dose constraints to provide an optimised method of sparing the small bowel during IMRT for rectal cancer.

Methods

Patients

The ethics board of the hospital approved the present study, and all of the investigations were conducted in accordance with the relevant guidelines and regulations. From March 2014 to March 2016, 24 patients with rectal cancer who underwent postoperative adjuvant radiotherapy were selected. The patient characteristics are summarised in Table 1.

Planning CT

CT scans (3 mm thick slices) of the patients' whole abdomen and pelvis were obtained with the treatment position on a Siemens Emotion-Duo CT simulator. Standard commercial immobilisation devices were applied. A carbon fibre frame and thermoplastic mask fixation (Pelvicast system, Orfit, Wijnegem, Belgium) was used. The patients were in the supine position with a pillow under their heads. Their knees and ankles were supported with vacuum cushions, and their arms resting on their chests. In the prone

position, a belly board (Civco Medical Solutions, Coralville, IA, USA) was applied to allow the abdomen to extend into its aperture. The patients were instructed to empty the bladder an hour before CT simulation. Gastrografin solution (600 mL) was administered orally an hour before scanning to better visualise the small bowel for delineation. CT scans were subsequently imported into the treatment planning system (Pinnacle 9.0, Philips Radiation Oncology, Fitchburg, MA. USA) for target delineation and treatment planning design. After the plan was confirmed, the patients were treated at the Medical Synergy Accelerator (Elekta Synergy, Elekta Oncology Systems, Crawley, UK). CT images were obtained and defined as 1W, 2W, 3W, and 4W, respectively, on the Friday of weeks 1-4 during treatment under the same scanning conditions.

Delineation of PS and BL

Per the delineation methods of small bowel from RTOG [17] and Robyn B [16], BL and PS were delineated for each patient's group of CT images. BL was delineated along the bowel loop's outer surface based on the contrast effect of Gastrografin solution and excluding the colon. The upper boundary was 1 cm above the superior level of the planning target volume (PTV), and the lower boundary was delineation of the small bowel until it ended. For the PS, the anterior and bilateral boundaries were the inner surface of the abdominal muscles, the posterior boundary was the vertebral body, sacrum, or sigmoid colon. The upper boundary was 1 cm above the superior PTV level. The lower boundary was parallel to the inferior sigmoid colon level. The PS included the small bowel and colon, but did not include the bladder, ovary, and uterus. A window width of 600 and window level of 40 were selected for delineation of the BL and PS and were completed by the same senior attending physician.

Target volume definition and treatment planning design

The target volume was delineated per the RTOG and NCCN guidelines [18-19]. The clinical target volume (CTV) included the lymphatic drainage area of the perirectal lymph nodes, presacral lymph nodes, and internal iliac lymph nodes, and some patients' external iliac lymph nodes were included. A margin of 1 cm in the cranial-caudal direction and 0.5 cm in the anterior-posterior and lateral directions was given to the CTV to form the PTV. The prescription was 50 Gy in 25 fractions to the PTV. In the Pinnacle 9.0 treatment planning system, 7 field IMRT plans were designed and called P_{PS} and P_{BL} and used as the PS (V_{15}<830 cc) and BL (V_{15}<275 cc) dose constraints, respectively [16]. Both plans used a 6 MV X-ray CC convolution algorithm and a 0.3 cm computational grid. An Elekta Synergy accelerator and 40 pairs of MLCs were selected. Dose constraints of V_{40}<50% and V_{50}<5% were used for the bladder and bilateral femoral head, respectively. The target dose coverage required more than 95% of the PTV covered by 100% of the prescription dose and a maximum dose (D_{max})<54 Gy inside and outside the PTV. The 1-4W CT images were fused with the Plan CT images, and the two P_{PS} and P_{BL} plans from the Plan CT were copied to the 1-4W CT images.

Evaluation of small bowel dose volume

The absolute irradiated volume (cc) of the small bowel was described by its volume exposed to 5-50 Gy with 5 Gy intervals. Each patient's small bowel volume (or irradiated volume) was expressed by the mean value over their CT images. All of the patients' small bowel volumes (or irradiated volumes) during treatment were expressed as their median volume values.

Evaluation of small bowel motion

The shift% was used to describe the small bowel movements, and shift%=SD/mean [20]. The SD and mean were the standard deviation and mean of the small bowel volume (or irradiated volume) from all of the CT images. A larger shift% signified greater motion of the small bowel during treatment.

NTCP prediction of small bowels

The Lyman-Kutcher-Burman (LKB) calculation module in Pinnacle 9.0 was used to predict chronic complications of the small bowel (called $NTCP_C$) [21-23]. The n (volume factor), m (slope of dose response curve), and TD_{50} (mean dose of 50% complication probability) parameters were set to 0.15, 0.16, and 55 Gy, respectively [24]. The complications were defined as small bowel obstructions, perforations, or fistulas. Logistic formula $NTCP=(1+(V_{50}/V)^k)^{-1}$ was used to calculate the acute toxicity of the small bowel based on its V_{15} (called $NTCP_A$), where V_{50} and k were 130 cc and 1.1, respectively [25]. Each patient's NTCP was expressed by the mean value over their all of the CT images. The NTCP of all of the patients during treatment was expressed by their median values.

Safety assessment of small bowel during treatment

V_{15}<275 cc from Robyn B et al. [16] and D_{max}≦54Gy were used as the criteria for safety evaluation of the small bowel during treatment. The small bowel was at risk when the value exceeded these criteria.

Statistical analysis

SPSS 19.0 software was used for the data analysis. Sigma Plot 10.0 and Microsoft Excel 2007 were used for figure plotting. A paired sample t-test was used to compare the differences between the two groups' data, and their correlation was analysed via Pearson's correlation coefficient. A two-tailed value of p<0.05 was considered statistically significant.

Results

PS and BL contours and treatment plans

Fig. 1 shows an example of a rectal cancer patient's PS and BL contours and dose distribution based on different CT images during treatment. A total of 109 sets of CT images were obtained for 24 patients, including 24 sets of Plan, 2W, and 3W images, 14 sets of 1W images, and 23 sets of 4W images. Overall, 218 contours containing the PS and BL were delineated for each patient. The median PS volume was 1339.28 cc (537.26-2121.71 cc) and the median BL volume was 250.27cc (81.00-590.79 cc) in all of the

patients. A total of 24 sets of P_{PS} and P_{BL} plans were designed based on Plan CT (218 sets of plans obtained after the plans copied to 1-4W CT scans). The median V_{15} of the PS from P_{PS} based on Plan CT was 918.96 cc (493.40-1324.55 cc), and 13 sets (13/24) were V_{15}>830 cc. The median V_{15} of the BL from P_{BL} based on Plan CT was 199.57 cc (73.31-275.71 cc). All of the dose constraints were met (the maximum value was 275.71 cc).

Evaluation of small bowel motion

The shift% of the BL and PS volumes was 28.46% (11.77%-80.78%) and 9.79% (2.75%-38.73%), respectively. The former was significantly larger than the latter (p=0.000). As shown in Fig. 2, the BL shift% of $V_{5\text{-}50}$ from 27.72%-57.15% was significantly larger than the PS of 8.89%-27.65% (top picture). The shift% of the BL and PS's V_{15} were 28.48% (4.78%-72.17%) and 11.79% (3.19%-42.83%) (p=0.000), respectively, and the shift% of the BL and PS's V_{30} were 35.23% (3.77%-88.79%) and 16.73% (4.21%-47.28%), respectively (p=0.000). The shift% of the BL and PS's V_{15} in the prone position was lower than in the supine position (25.24% vs 32.10%, p=0.000; 9.9% vs 14.85%, p=0.000).

Dose volume and NTCP of small bowels

Table 2 compares the dose volume and NTCP of the small bowels between P_{PS} and P_{BL} in 24 patients with rectal cancer during IMRT. In $V_{5\text{-}50}$, the dose volume of P_{PS} was lower than that of P_{BL} except V_{25} and V_{50}, and V_{15} was 170.07±49.98 cc vs 178.58±47.13 cc (T=-6.355, p=0.000). D_{max} was 53.43±0.28 Gy vs 53.46±0.37 Gy (T=1.183, p=0.248). As shown in Fig. 3, there was a significant correlation of V_{15} between the PS and BL in both P_{PS} and P_{BL} (R=0.455, p=0.000).

The median $NTCP_C$ and $NTCP_A$ of P_{PS} and P_{BL} were 2.80% (0.00%-12.00%) and 57.32% (34.86%-67.19%), and 3.00% (0.00%-10.75%) and 58.64% (37.94%-67.33%), respectively. $NTCP_C$ and $NTCP_A$ from P_{PS} were significantly less than from P_{BL} (2.80% vs 3.00%, T=-2.538, p=0.018; 57.32% vs 58.64%, T=-4.494, p=0.000).

In the prone and supine positions, most of the dose volume and NTCP of the small bowel from P_{PS} were less than from P_{BL}, and the p values of V_{10}, V_{15}, V_{30}, and $NTCP_A$ were less than 0.05 (Table 3).

Safety assessment of small bowels during treatment

As shown in Fig. 4, V_{15} of the small bowel from P_{PS} exceeded 275 cc 3 times (3/109) during treatment, with a maximum of 311.27 cc (over 13.18%). V_{15} from P_{BL} exceeded 275 cc 4 times (4/109), with a maximum of 340.97 cc (over 23.99%). D_{max} of the small bowel >54 Gy from the P_{BL} and P_{PS} plans 4 times, and the maximum value was 54.37 Gy and 54.25 Gy, respectively.

Discussion

Because the small bowel is a radiosensitive organ, acute and chronic side effects may occur during rectal cancer radiotherapy. The side effects can be reduced by limiting the dose volume. However, evaluating the small bowel dose volume can be challenging. Characteristics of small bowel movement may weaken the dose-limiting function. The small bowel loops do not remain in the same positions at all times. They experience both oscillating displacements of the wall due to peristalsis and large amplitude shifts due to changes in content. The frequency of peristalsis can reach 8–11 times per minute, and it can combine into complex forms of motion at different times and spaces [26]. Small bowel movements have to be taken into account when evaluating the dose volume by contouring the BL, while the peritoneal space can account for any potential region that may be occupied by the small bowel and covering its movements, so it replaces the BL for dose constraints with clinical significance.

In this study, we first evaluated small bowel movement during treatment. The results showed that all of the shift% of the BL were larger than 27%, while most shift% of the PS were below 20%(V_{5-45}), and shift% in the prone position was significantly lower than in the supine position (Fig. 2). Kvinnsland et al. studied the dose volume changes in the small bowel through 6 to 8 repeated CT scans in 10 patients with bladder cancer. Their results showed that the relative standard deviations of $V_{30.8}$, $V_{49.5}$, and $V_{53.5}$ were 20%, 24%, and 26%. respectively. The authors believed that small bowel dose limitations should be carefully considered when variations in the irradiation volume exceeded 20% [27]. Sanguineti et al. confirmed small bowel movement during prostate cancer radiotherapy by continuous CT scanning. The results showed that 280 cc of the small bowel completely changed position on planned CT, while only 20% remained in its original position [28].

The movement characteristics of the small bowel make it necessary to explore the reliability of the PS dose limit method for small bowel sparing in IMRT. The results showed that there was similarity on D_{max} while the V_{15} times exceeded the P_{PS} limits during 1-4W less than in P_{BL}. The maximum exceeding value from P_{PS} was lower than from P_{BL} (13.18% vs 23.99%), indicating that the PS limit method was superior to the BL method for small bowel safety.

Our results showed that most of the dose volume and NTCP of the small bowel from P_{PS} were smaller than from P_{BL}, and the dose constraint may be one of the reasons. Although the recommended dose constraint from Robyn B was used in this study [16], there are slightly different research methods and irradiation techniques between the two. The PS dose and small bowel with PTV 45 Gy followed by tumour 5.4 Gy boost in the literature may be lower than the present study (50 Gy PTV dose), while the four-field conformal technique may lead to a higher dose than the IMRT technique used in this study. V_{15} < 830 cc used as the dose constraint in this study was relatively strict, approximately half of the plans (13/24) exceeded this standard, and the median value exceeded 10.71%. The results showed that the small bowel dose volume could be further reduced by strictly limiting the PS dose when designing P_{PS} and it is appropriate to use V_{15} < 830 cc as the dose constraint.

A dose constraint of V_{15} < 275 cc in P_{BL} is relatively easy to achieve. Robyn B et al. thought that 275 cc was larger than previous studies (120 cc-150 cc). On the one hand, this may be because the subject of their study was preoperative patients and surgery may lead to more enteritis. On the other hand, the reason may be the upper bound of the BL 1.5 cm above the superior PTV level. Regarding the upper boundary of the PS and BL, Robyn B defined 1.5 cm above the PTV [16] while our study used RTOG of 1.0 cm[17]. There was no substantial difference between 1.0 cm and 1.5 cm because coplanar IMRT technology and absolute volume (cc) evaluation were used in this study. An upper boundary larger than 1 cm above the PTV should be adopted when using non-coplanar irradiation, while 2–5 cm should be used for tomotherapy [17].

The supine and prone position with a belly board are common therapeutic positions in IMRT for rectal cancer. The respective statistical results of the two positions (Table 3) were similar to those of all of the patients (Table 2). Most of the small bowel dose volume and NTCP from P_{PS} were smaller than from P_{BL}, and there were significant differences in V_{10}, V_{15}, V_{30}, and $NTCP_A$. This shows that the PS limitation method has advantages in both the supine and prone positions. However, the small bowel dose volume and NTCP in the prone position were significantly lower than in the supine position, consistent with previous studies [29–32]. Nevertheless, the design reproducibility and target dose coverage were significantly superior in the supine position. Some studies reported that patient positioning in RT for rectal cancer patients may therefore be selected based on other factors such as the most comfortable position for the patients [32–33].

The PS defined in this study included the small bowel, colon, and space between the intestines. The PS used objectively in IMRT planning can reduce the overall PS dose volume, making it easier to reduce the small bowel dose. It reduces high dose irradiation caused by small intestinal movement during treatment, so it has an advantage over the BL limit. which uses only the small bowel as the objective function. Further research showed that there was a significant correlation of V_{15} between the PS and BL ($R = 0.455$, $p = 0.000$), indicating that the PS can replace the BL as the objective function of the dose constraint in IMRT planning. However, when using the PS limit, attention should be paid to the occurrence of PS dose hotspots in the absence of BL evaluation, especially when the dose limits are more stringent, and dose hotspots in PS must be evaluated and avoided to prevent excessive small bowel irradiation.

Conclusions

Our findings demonstrated that small bowel motion may lead to uncertainties in its dose volume and NTCP assessment during IMRT for rectal cancer. The BL movements were significantly greater than the PS and significantly smaller in the prone position than in the supine position. It is feasible to use the PS instead of the BL limit to spare the small bowel. V_{15} < 830 cc can be used as the dose constraint standard.

Abbreviations

PS
peritoneal space;
BL
bowel loops;
IMRT
intensity-modulated radiotherapy;
NTCP
normal tissue complication probability;
QUANTEC
Quantitative Analysis of Normal Tissue Effects in the Clinic;
CT
Computed Tomography;
RTOG
Radiation Therapy Oncology Group;
PTV
planning target volume;
MLCs
multi-leave collimators;
NCCN
The National Comprehensive Cancer Network;
CTV
clinical target volume;
P_{PS}
plans were designed by using dose constraints of the PS (V15 < 830 cc);
P_{BL}
plans were designed by using dose constraints of the BL (V15 < 275 cc);
D_{max}
maximum dose;
$NTCP_C$
chronic complication probability of the small bowel;
$NTCP_A$
acute complication probability of the small bowel;
$V_{30.8}$, $V_{49.5}$, $V_{53.5}$
Volume receiving at least 30.8 Gy, 49.5 Gy, 53.5 Gy;
V_{10}, V_{15}, V_{30}
Volume receiving at least 10 Gy, 15 Gy, 30 Gy;

Declarations

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Not applicable.

Authors' contributions

SL, and YG: project conception and design, data collection, assembly, analysis and

interpretation, manuscript writing. YY, and QG: data collection and assembly. JQ, and YT revised and approved the final manuscript. All authors read and approved the final manuscript.

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Availability of data and materials

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

The study was approved by the ethics committee of The Second Affiliated Hospital of Soochow University (2014047).

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Tables

Table 1. Patient characteristics

Variable	*n*	%
Gender		
Male	15	62.5
Female	9	37.5
Age (y)		
Range	39-77	/
Median	58.5	/
T stage		
T2	4	16.7
T3	18	75.0
T4	2	8.3
N stage		
N0	8	33.3
N1	13	54.2
N2	3	12.5
Clinical stage		
	10	41.7
	14	58.3
Treatment position		
Supine	12	50.0
Prone	12	50.0

Table 2. Comparison of the small bowel dose volume and NTCP between P_{PS} and P_{BL} in 24 patients with rectal cancer during IMRT

	P_{PS}	P_{BL}	T	*P*
V_5 (cc)	248.73±112.33	250.27±115.92	-1.790	0.085
V_{10} (cc)	223.43±77.61	236.72±95.05	-3.060	0.005
V_{15} (cc)	170.07±49.98	178.58±47.13	-6.355	0.000
V_{20} (cc)	139.16±46.24	159.02±54.19	-2.185	0.039
V_{25} (cc)	112.28±42.58	109.45±43.25	2.501	0.019
V_{30} (cc)	82.33±37.5	83.2±37.88	-4.212	0.000
V_{35} (cc)	63.91±32.51	68.12±31.18	-1.652	0.111
V_{40} (cc)	50.49±28.38	54.16±29.39	-2.625	0.015
V_{45} (cc)	37.16±24.02	42.22±25.81	-4.040	0.000
V_{50} (cc)	21.62±18.3	21.00±18.12	0.172	0.864
D_{max} (Gy)	53.43±0.28	53.46±0.37	1.183	0.248
$NTCP_C$ (%)	2.80±2.54	3.00±0.02	-2.538	0.018
$NTCP_A$ (%)	57.32±8.73	58.64±7.72	-4.494	0.000

Table 3. Comparison of the small bowel dose volume and NTCP between prone and supine patients

	Supine position				Prone position			
	P_{PS}	P_{BL}	T	*P*	P_{PS}	P_{BL}	T	*P*
V_5 (cc)	361.00±113.20	362.48±117.71	-1.97	0.074	207.99±62.00	208.70±63.35	-0.32	0.748
V_{10} (cc)	262.41±78.49	289.10±98.75	-2.43	0.033	191.43±58.24	203.55±61.95	-5.06	0.000
V_{15} (cc)	176.57±47.18	180.68±46.72	-3.91	0.002	159.95±51.13	172.83±47.74	-4.50	0.000
V_{20} (cc)	139.16±44.69	196.58±57.65	-2.61	0.023	134.73±49.64	144.42±49.60	-0.08	0.931
V_{25} (cc)	112.75±41.91	109.45±46.10	-1.63	0.130	110.25±44.99	112.56±42.10	-1.82	0.094
V_{30} (cc)	86.78±38.64	91.17±42.22	-2.45	0.031	76.63±37.94	81.95±34.72	-3.48	0.005
V_{35} (cc)	67.47±34.07	72.67±33.98	-1.11	0.287	60.34±32.38	62.44±29.62	-1.16	0.266
V_{40} (cc)	52.35±29.16	57.80±32.33	-3.20	0.008	47.54±28.87	49.21±27.42	-0.61	0.549
V_{45} (cc)	38.82±24.69	47.90±27.80	-0.18	0.856	36.64±24.39	37.63±24.64	0.46	0.652
V_{50} (cc)	21.28±20.39	20.50±18.73	0.95	0.361	23.02±16.80	22.64±18.32	-1.16	0.269
$NTCP_C$ (%)	4.90±2.88	4.78±2.59	-1.36	0.201	2.30±1.61	2.70±1.67	-2.54	0.027
$NTCP_A$ (%)	58.34±7.07	58.95±6.70	-3.12	0.009	55.67±9.84	57.77±8.65	-4.05	0.005

Figures

Figure 1

An example of a rectal cancer patient's PS and BL contours and dose distribution based on different CT scans during treatment. The green, blue, and orange contours represent PTV, PS, and BL, respectively. The

innermost and outermost dose lines are 50 Gy and 30 Gy, respectively. 1A and 1B present PPS and PBL, respectively, based on Plan CT. 1C, 1D, 1E, 1F, 1G, 1H, 1I, and 1J present PPS and PBL based on 1-4W CT during treatment, respectively.

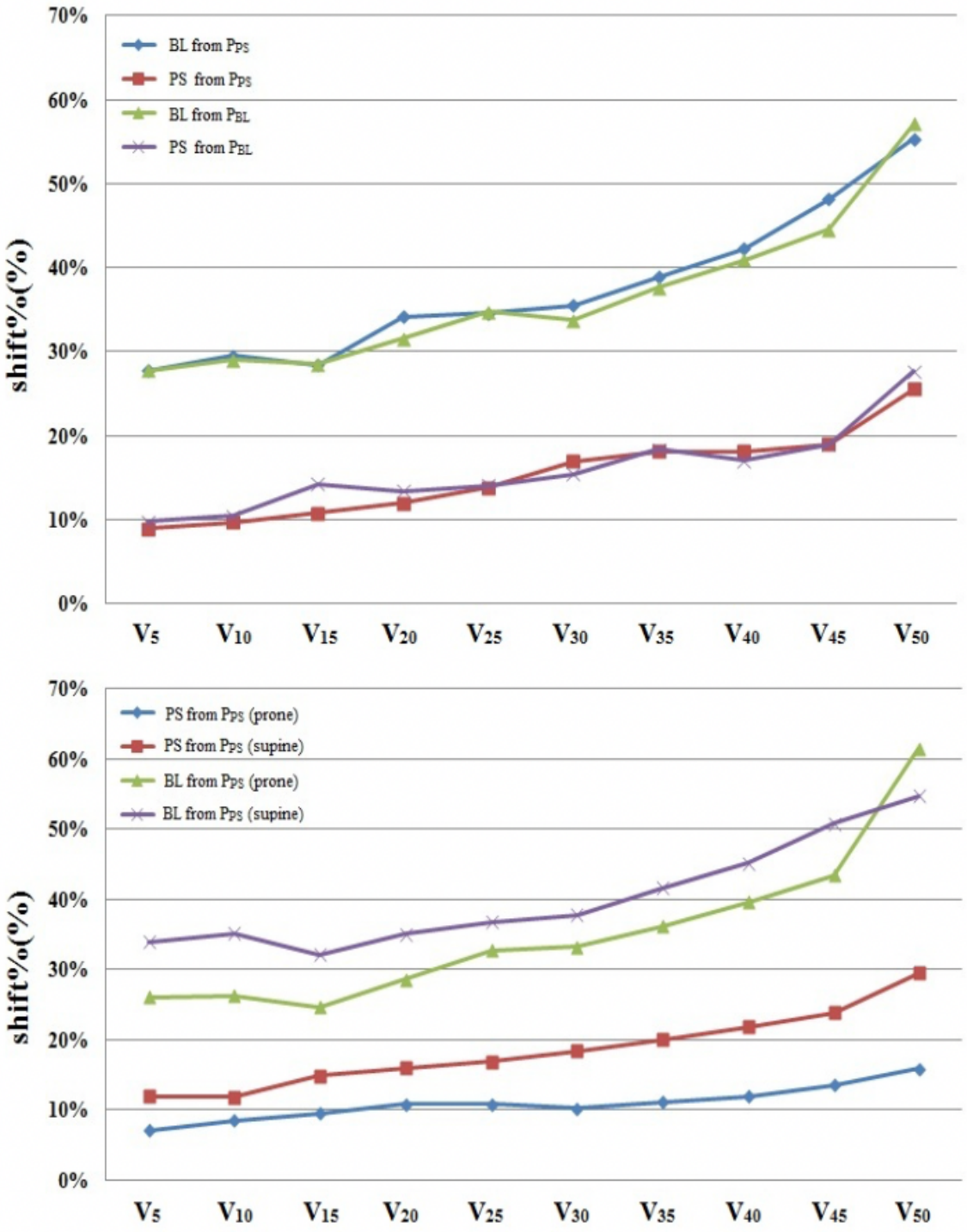

Figure 2

The shift% of the BL and PS during treatment. The blue, green, purple, and red lines in the top image represent the shift% of the BL from PPS, the shift% of the BL from PBL, the shift% of the PS from PBL,

and the shift% of the PS from PPS, respectively. The purple, green, red, and blue lines in the bottom picture represent the shift% of the BL from PPS in the supine position, the shift% of the BL from PPS in the prone position, the shift% of the PS from PPS in the supine position, and the shift% of the PS from PPS in the prone position, respectively.

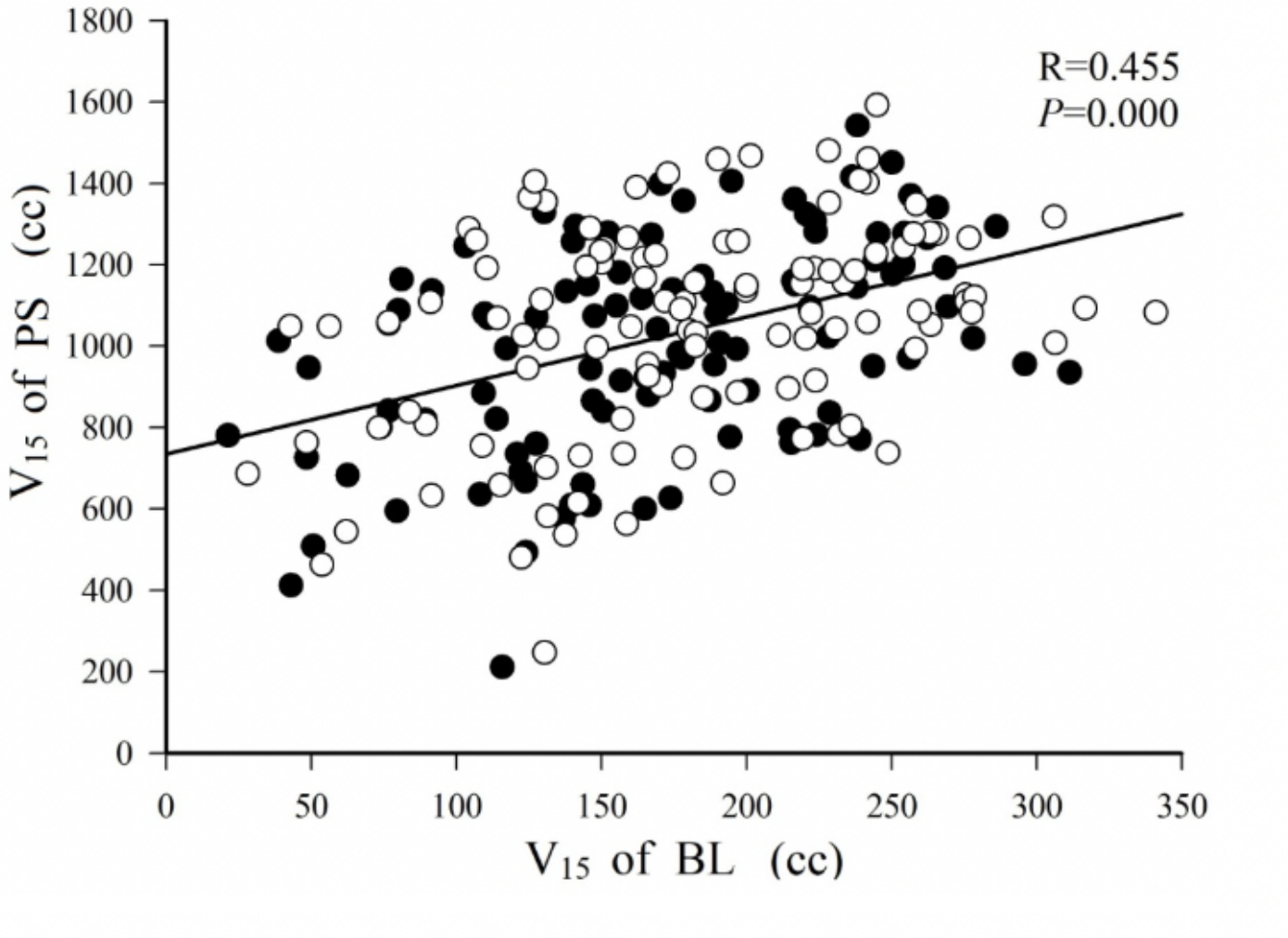

Figure 3

Correlation of V15 between the PS and BL in both PPS and PBL based on all of the CT images. ● and ● represent V15 from PPS and PBL, respectively.

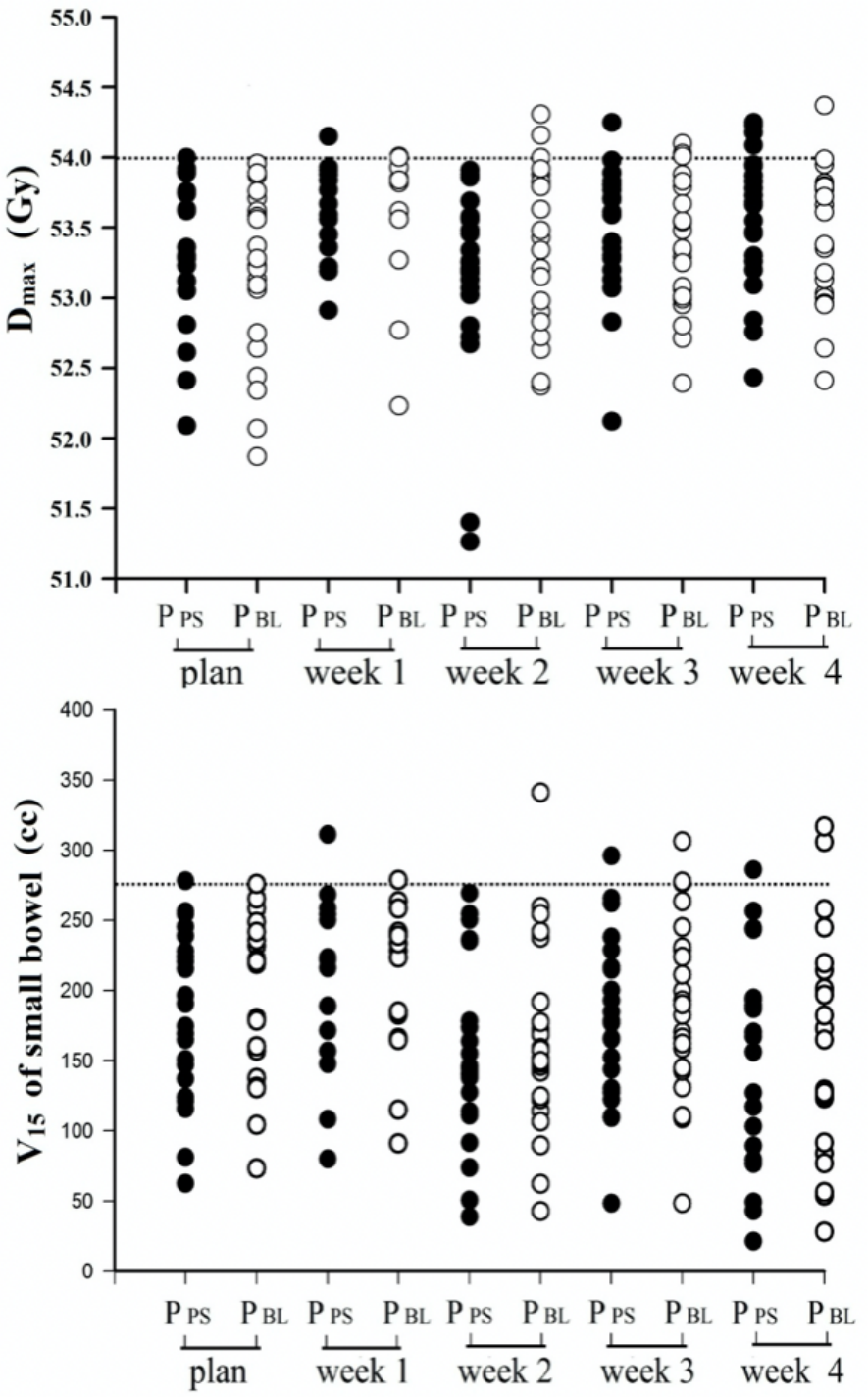

Figure 4

Safety assessment of the small bowel in 24 patients with rectal cancer during treatment. The top and bottom images are the Dmax and V15 estimation, respectively.