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3D conformal planning using low segment multi-criteria IMRT optimization

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Abstract

Purpose—To evaluate automated multicriteria optimization (MCO) – designed for intensity modulated radiation therapy (IMRT), but invoked with limited segmentation – to efficiently produce high quality 3D conformal radiation therapy (3D-CRT) plans.

Methods—Ten patients previously planned with 3D-CRT to various disease sites (brain, breast, lung, abdomen, pelvis), were replanned with a low-segment inverse multicriteria optimized technique. The MCO-3D plans used the same beam geometry of the original 3D plans, but were limited to an energy of 6 MV. The MCO-3D plans were optimized using fluence-based MCO IMRT and then, after MCO navigation, segmented with a low number of segments. The 3D and MCO-3D plans were compared by evaluating mean dose for all structures, D95 (dose that 95% of the structure receives) and homogeneity indexes for targets, D1 and clinically appropriate dose volume objectives for individual organs at risk (OARs), monitor units (MUs), and physician preference.

Results—The MCO-3D plans reduced the OAR mean doses (41 out of a total of 45 OARs had a mean dose reduction, $p < 0.01$) and monitor units (seven out of ten plans have reduced MUs; the average reduction is 17%, $p = 0.08$) while maintaining clinical standards on coverage and homogeneity of target volumes. All MCO-3D plans were preferred by physicians over their corresponding 3D plans.

Conclusion—High quality 3D plans can be produced using MCO-IMRT optimization, resulting in automated field-in-field type plans with good monitor unit efficiency. Adopting this technology in a clinic could improve plan quality, and streamline treatment plan production by utilizing a single system applicable to both IMRT and 3D planning.

Keywords

3D-CRT; MCO; Pareto; IMRT

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COI: Fazal Khan, nothing to declare.

1 Introduction

3D planning is a standard approach for delivering conformal radiotherapy to a variety of cancers. The simplicity, low cost, low maintenance and well documented outcomes of 3D planning have made it the preferred choice for many disease sites. In 3D planning, dose distribution changes are generated by manually modifying treatment parameters such as field shapes, beam weights, beam modifiers, and scaling.

The 2000s saw a growing interest in IMRT (intensity modulated radiation therapy), a computer optimized method of delivering radiation [1] which modulates radiation from each field using a multi-leaf collimator (MLC), permitting greater conformality and better OAR sparing. However IMRT comes with its own challenges including greater sensitivity to motion [2, 3], more complex dosimetry, potentially higher monitor units and treatment time [4], increased quality assurance (QA) complexity and greater machine wear-and-tear [5]. IMRT can cost anywhere from 1.5 to four times the amount of a 3D plan [6, 7, 8], and in the United States resistance from insurance companies to reimburse for IMRT may add to the persistence of 3D conformal therapy. [9]. Some disease sites, notably prostate and head-and-neck, have moved to IMRT planning for the majority of their cases, but many common sites such as breast and lung remain in the 3D planning realm.

Due to the manual manipulation required in 3D planning it can be time-consuming to find a desirable dose distribution. Also, once a plan is created there is no way of confirming whether the plan is fully optimized. By 'fully optimized' we refer to a plan where any improvement of one criteria – eg. homogeneity or OAR dose – must come at the expense of worsening another planning criteria. This requirement is known as Pareto optimality. The set of Pareto optimal plans is called the Pareto surface and navigating this surface has become a valuable technique for IMRT planning [10, 11].

Pareto navigation hinges on averaging multiple plans, making IMRT an ideal modality since fluence maps can be averaged, which leads to the averaging of dose distributions. Because common 3D conformal sites require only a small amount of intensity modulation, we hypothesize that using fluence map based MCO and a low number of segments will allow us to use the MCO-IMRT planning technique to generate high quality 3D plans, achieving the best of two worlds: the relative simplicity of 3D plans with the power of numerical optimization of MCO-IMRT.

2 Methods and materials

2.1 Case selection

Ten recently planned patients of brain, breast, lung, abdomen and pelvis disease sites were selected from our institutional clinical database. The clinically treated 3D plans were used as our baseline comparison. These plans are described in Table 1, along with the relevant planning information including prescriptions and beam information.

2.2 Structure Definitions

Physician-drawn target volumes and OARs as well as the original dosimetrist-generated target expansion volumes were used to plan and evaluate all plans. For the MCO-3D cases additional planning structures were created. Each MCO-3D plan contained a structure expanded from the PTV radially to the edge of the CT scan but only 4cm superiorly and inferiorly, creating a wide cylindrical volume. This structure, called 'falloff', was used to promote dose conformity. Some MCO-3D plans used an additional 2-3cm wall expansion around the PTV, called 'PTVwall', for additional sharpening of the high-dose conformity.

2.3 Planning Parameters

XiO (v4.4; Elekta, Stockholm, Sweden) was used for the original 3D plans, which were the clinically used plans. RayStation (v2.5; RaySearch Laboratories, Stockholm, Sweden) was used to optimize and calculate all MCO-3D plans. The MCO-3D plans matched the original 3D plans in terms of machine (Varian or Elekta) and beam geometry. The MCO-3D plans did not use any wedges and were limited to an energy of 6 MV. All dose computations were done in their respective planning systems, which both employ heterogeneity corrections, and are sent through the same set of commissioning tests, which include heterogeneity phantoms, MLC transmission tests, and IMRT specific tests such as picket fence irradiations. Additionally, during the clinical commissioning of RayStation, plans from XiO were imported and recomputed in RayStation to verify that the dose differences between the two systems are negligible (within 2%).

Pareto surface-based MCO uses the paradigm of objectives and constraints. Constraints are criteria which cannot be violated, while objectives are functions which are minimized or maximized subject to the constraints. All OARS were assigned a 'minimize the equivalent uniform dose (EUD)' objective [12, 13]. EUD for an organ with n equi-sized voxels, each receiving d_i dose, is given by

$$EUD = \left(\frac{1}{n} \sum d_i^a \right)^{1/a}$$

where a is a parameter generally chosen to be greater than or equal to 1. If $a = 1$, the EUD is the mean dose to the organ. In the limit of $a \rightarrow \infty$, the EUD approaches the maximum dose of the organ. We used $a = 2$ which is a standard approach to controlling both the mean dose and the hotspots.

For the falloff structure we used the 'dose-falloff' objective. This objective penalizes doses outside the target by specifying a desired dose falloff rate (as a linear function of distance to the target). Voxels which violate this dose falloff are penalized quadratically based on their deviation.

All MCO-3D plans were optimized with the original 3D plan's goals in mind. In the cases where the PTVwall structure was used, this structure was given an EUD objective with an a value ranging from 20-30. Targets were given both objectives and constraints. The target objectives consisted of a minimum dose objective, which is a quadratic penalty on voxel

underdosage, and a uniform dose objective (the standard two-sided quadratic penalty), both at the prescription dose. The target constraints included a dose-volume constraint of at least 95% of the volume receiving the prescription dose and a minimum target dose of 95% of the prescription. Lastly, a constraint was given on the falloff volume as a maximum dose equal to 105% of the prescription dose.

RayStation computes a user-specified number of plans that optimize different weighted sums of the objectives in order to create a representation of the Pareto surface. We used $4 \times (\text{number of objectives})$ plans for each Pareto surface. After navigation, RayStation's direct machine parameter optimization is invoked to determine jaw placement and MLC segment shapes/weights to best create the navigated-to dose.

2.4 Determination of the number of segments

We opted to allow the MCO-3D plans additional segments to allow the MCO-3D plans to compete more fairly with the standard 3D conformal plans, determined as follows:

1. One segment per beam angle in the original 3D plan
2. One segment per field-in-field used in the original 3D plan.
3. We added the number of fields using higher energies (HE) than 6 MV to the number of wedges (W) to get "HE+W", then added additional segments to the MCO-3D plan based on the following.
 - If the HE+W = 1-2, we added 1 additional segment
 - If the HE+W = 3-5, we added 2 additional segments
 - If the HE+W = 6+, we added 3 additional segments

2.5 Evaluation

We evaluated each plan by comparing mean dose for all structures. Additionally, for targets, D95 (defined below) and homogeneity indexes were compared. For OARs where maximum dose is important, D1 is also reported; if OARs have standard dose-volume criteria, those values are reported. The homogeneity index (HI) is defined as:

$$HI = (D_5 - D_{95}) / D_p$$

where D_x is the dose to $x\%$ of the PTV and p is the prescription dose. MUs and physician preference were also compared.

The doses were exported to MiMVista (Version 6.0, Cleveland, OH) for evaluation in order to eliminate differences in DVH computations by the two planning systems.

3 Results

3.1 Case results

For each case we highlight notable planning aspects. Dose and MU comparison data for all cases are summarized in Table 2. We display dose distributions and DVH comparisons for

four of the cases (brain case 2, breast case 2, thoracic case 1, pelvis case 1), selected to show a range of results, not necessarily the best results.

Brain cases—In brain case 1, MCO-3D lowered the left and right cochlea mean dose by 5.5Gy and 3.6Gy, respectively. D1 values were also lowered for left and right cochleas by 6.9Gy and 5.6Gy, respectively. This sparing came at the price of a reduction in homogeneity, an HI of 0.07 compared to 0.03 for the original plan.

In brain case 2, the D1 and mean doses of the chiasm, right cochlea and right optic nerve each were lowered by roughly a factor of three. As in brain case 1, the OAR sparing came at the price of an increase in the homogeneity index, from 0.04 to 0.06. The comparison between the original 3D plan and the MCO-3D plan for brain case 2 is shown in Figure 1.

Breast cases—In breast case 1, the MCO-3D plan was able to improve breast coverage at prescription dose by 15%, while simultaneously reducing lung dose. The HI was improved from 0.31 to 0.18.

Similar to case 1, in breast case 2 the MCO-3D demonstrated superior breast coverage while simultaneously lowering whole heart, left ventricle, left anterior descending artery (LAD) and lung dose. Once again, hotspots remained similar to the original plan and HI improved from 0.43 to 0.21. The plan comparison is shown in Figure 2.

Thoracic cases—In thoracic case 1, the MCO-3D reduced every OAR, most notably the right lung V20, which decreased by 6.7 percentage points (pp), and the atria V25 which decreased by 14.5pp. The plan comparison is shown in Figure 3.

In thoracic case 2, the MCO-3D lowered the mean dose of every OAR, although not as significantly as in thoracic case 1. Atria V25 decreased from 36.1% to 24.9%. MCO-3D increased the homogeneity index by 0.02, however difficulties were encountered with high dose building up near the skin. A 2cm inner wall contour helped control this.

Abdomen cases—In abdomen case 1, the MCO-3D plan lowered the mean dose of most OARs. The combined kidney V10 was lowered from 17.8% to 10.3%. The spinal cord D1 increased from 12.3Gy to 18.8Gy, which is still well below spinal cord tolerance doses, and allows for the other OAR improvements. HI increased from 0.06 to 0.07.

In abdomen case 2, MCO-3D significantly lowered all OAR mean doses. The homogeneity index rose from 0.05 to 0.08.

Pelvis cases—In pelvis case 1, the rectum V55 was lowered 16.3pp, from 38% to 21.8% in the MCO-3D plan. The bladder mean dose was lowered from 64.6Gy to 57.7Gy. Femoral head mean doses were also lower in the MCO-3D plan, although the femoral head volume receiving doses above 40 Gy went up in the MCO-3D plans due to the higher lateral entrance doses. HI was unchanged. The comparison between the plans for pelvis case 1 is shown in Figure 4. Table 2 shows that the original 3D plan's PTV mean dose could be scaled down by about 1.5Gy to better match the MCO-3D PTV mean dose. This would reduce the

improvement seen by the MCO-3D plan, but the MCO plan would still outperform the original plan in all of the above criteria.

In pelvis case 2, the MCO-3D was able to reduce the mean dose to all OARs, especially the femoral heads. The HI increase in this plan was the greatest, from 0.05 to 0.09.

3.2 Statistical analysis

In both planning methods we intentionally maintain target coverage at the clinical requirements, thus we apply statistical analyses to the OAR doses. Since the data set contains only two of each case type, and even within the same case type the OARs are not consistent, we use the following for our statistical hypotheses: Null: there is no systematic change regarding OAR doses, Alternate: the MCO-3D method improves OAR doses. Due to the varieties of OARs and dose levels to those OARs, a t-test is not a valid approach (both normality and independence are violated), so we use a binary outcome measure (did the OAR do better or worse with MCO-3D). Under the null hypothesis any given OAR has a 50% chance of doing better or worse under MCO-3D planning, which gives rise to binomial statistics. While this necessarily ignores the magnitudes of the dose improvement, these are found in Table 2. Taken as one data set and considering the mean dose to all OARs (using instead the dose-volume criteria in Table 2 does not change the results) the null hypothesis is rejected at a p-value $\ll .001$. We can look at each site individually (here we must use mean doses since there are not enough dose-volume criteria if sites are examined individually) and there we find statistically significant results for the thoracic ($p \ll .001$), abdominal ($p=0.046$) and pelvic ($p=0.004$) cases. For the breast, although all OARs improved, the small number of OARs involved (a total of 4) is not large enough to produce statistical significance ($p=.06$). For the brain, case 2 saw a slight (but clinically insignificant) increase in mean doses to the left cochlea and left optic nerves, which led to a p-value of 0.14. Note however that brain case 1 saw improvements in all OARs.

3.3 Physician preferences and Monitor Units

After the MCO-3D plans were generated they were coupled with their original 3D plans and sent back to the treating physician to ask which plan they preferred. In all ten cases the physicians selected the MCO-3D plans over the original 3D plans.

IMRT is typically associated with higher MUs than 3D conformal planning. In our ten cases however, this trend did not occur. Although not statistically significant at the $p=0.05$ level, we find that our MCO-3D plans, produced via IMRT optimization, had overall fewer monitor units ($p=0.08$) than the original 3D plans. The average MU of the original 3D plans was 313 while the average MU of the MCO-3D plans was 259, a 17.3% decrease. This average MU was taken from the average of all cases ten cases (five different anatomical sites) and is presented to show the reduction that may be achieved with MCO-3D. Among the five sites, the brain site had the most significant total reduction in MUs for MCO-3D, with a combined total of 284 fewer MUs (43.6% decrease). The least change in MUs was for the breast site, which had a combined total of 2 more MUs (0.8% increase) for MCO-3D. For a single case, the most significant reduction in MUs was for brain case 2 which showed a reduction of 190 MUs (54.6% decrease) using MCO-3D. The highest increase we

observed in a single case was for pelvis case 1, where the MCO-3D plan increased MUs by 34 (15.6% increase). Seven of the ten cases saw an improvement in MUs using the MCO-3D technique. See Table 2 for details.

4 Discussion and Conclusions

Photon treatments are typically classified as either 3D conformal or IMRT. However it is more useful to think of these modalities as lying along a span of treatment possibilities, from simple to complex [15]. Although IMRT lies on the complex end of this spectrum and has historically been considered more difficult than 3D planning, IMRT planning can often be easier since software and computation power have improved dramatically in the last decade. Considering this, we speculated and showed that if IMRT optimization were used – in particular MCO – we would be able to derive good 3D solutions from the selected IMRT plan if that plan would not require much intensity modulation.

We observed that MCO-3D generally reduced OAR mean doses, achieved comparable target doses and homogeneity, and reduced MUs compared to manual 3D planning. However due to the fact that only two cases per anatomical site were planned, we recognize that this work can only be considered a pilot investigation, and that clinics considering adopting this technique should validate it on a site by site basis to determine its applicability.

If able to be billed and quality assured as 3D (in the United States there are insurance and reimbursement differences between these modalities), we recommend MCO-3D for all 3D cases which utilize three or more fields and for which there is a well defined target. Though we planned a limited number of sites/cases, we were most impressed by the result of Pelvis case 1 (4-field box type treatment). Another excellent and very relevant fit for MCO-3D would be patients who would benefit from IMRT, but cannot receive it – because of financial, technological or patient-specific limitations – and therefore must receive standard 3D.

A single planning system used for both 3D and IMRT would be beneficial from the perspectives of plan production streamlining, training and QA. Fewer systems means an overall operation that is easier to monitor and less prone to error [16, 17]. Currently the full spectrum of complexity between 3D plans and IMRT plans is not fully explored in the clinic, but our approach indicates that it could be, since we use the same underlying algorithm for MCO-3D as we do for IMRT. A plan should be as complex as necessary to achieve a desired level of dose quality. QA procedures should be standardized and take the form of independent software – such as a Monte Carlo system – in order to verify all plans [18, 19], thus eliminating the QA distinction between 3D and IMRT.

In modern clinics, IMRT has become the clinical standard for sites which most strongly benefit from being able to shape the dose distribution to avoid nearby OARs. However, all sites could benefit from some intensity modulation, which is why 3D therapy has evolved to include FIFs, wedges and higher energies, which provide dose control similar to IMRT [20]. For all of the sites studied in this paper, IMRT has been explored [9, 21, 22, 23] and is often used, but 3D remains a common modality. One likely reason is that IMRT may seem overly complex, more costly and less efficient for the treatment goals in mind. Our technique on the

other hand depends on the idea that a little intensity modulation goes a long way, as brought to light by studies which point out the diminishing returns one gets from more complexity [24, 25, 26, 27]. Our planning method allows the customizability and dosimetric benefits of MCO-IMRT with the simple and robust delivery of 3D conformal therapy.

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Figure 1. Axial dose distribution and DVH comparison for brain case 2. The red arrows highlight MCO-3D pushing low dose away from critical organs.

Figure 2.
Axial dose distribution and DVH comparison for breast case 2.

Figure 3. Axial dose distribution and DVH comparison for thoracic case 1. The circled regions indicate areas where MCO-3D sculpts the dose distribution to conform to the PTV.

Figure 4.

Axial dose distribution and DVH comparison for pelvis case 1. The red arrows show that the MCO-3D plans are able to push dose out of the rectum.

Table 1

Case descriptions, prescriptions, and beam settings for the ten patient cases.

Site	Case #	Sub-site	Prescription (Gy)	# of Beam Angles	Beam Arrangement	# of Field-in-Fields (FIF) used in 3D Plan	# of High Energy (HE, >6MV) beams used in 3D Plan	# of Wedges (W) used in 3D Plan	HE+W
Brain	Case 1	Cerebellum	20	4	coplanar	2	6	4	12
	Case 2	Left Parietal	60	5	4 coplanar, 1 superior vertex	0	1	3	4
Breast	Case 1	Right Breast	50	2	tangents	0	0	0	0
	Case 2	Left Breast	50	2	tangents w/FIF	2	2	0	2
Thoracic	Case 1	Right Lung + Mediastinum	42	5	1 AP, 4 obliques	0	5	4	9
	Case 2	Esophagus	55	4	4 posterior-lateral obliques	0	4	4	8
Abdomen	Case 1	Pancreas	30	4	various obliques	0	4	3	7
	Case 2	Pancreas	45	5	various obliques	0	5	2	7
Pelvis	Case 1	Prostate Fossa	64.8	4	4 field box	0	3	0	3
	Case 2	Bladder Bed	39.6	3	1 PA and 2 laterals	0	3	2	5

The final column, the number of segments used in the MCO-3D plans, is derived from the FIF and HE+W columns, using the logic as described in section 2.4.

Table 2

Dosimetric and monitor unit (MU) comparisons for all ten patient cases.

		ORIG-3D	MCO-3D	% decrease
Brain 1	HI	0.03	0.05	-66.7
	(Posterior Fossa)			
	Target D95	20.34	19.96	1.9
	Target mean	20.64	20.57	0.34
	Left Cochlea	16.66/D1=18.95	11.21/D1=12.10	32.7/36.1
	Right Cochlea	14.39/D1=16.60	10.82/D1=11.05	24.8/33.4
	Combined OARs	15.68	11.04	29.6
Brain 2	MU	303.6	209.2	31.1
	HI	0.04	0.06	-50
	Target D95	60.92	60.05	1.4
	Target mean	62.35	61.79	0.9
	(Left Parietal)			
	Brainstem	17.97/D1=54.49	14.48/D1=54.34	19.4/28
	Chiasm	9.61/D1=11.43	3.5/D1=4.64	63.6/59.4
	Left Cochlea	3.16/D1=4.77	4.56/D1=5.28	-44.3/10.7
	Right Cochlea	9.38/D1=9.58	2.87/D1=3.05	69.4/68.2
	Right Optic Nerve	4.58/D1=9.24	1.52/D1=2.74	66.8/70.3
	Left Optic Nerve	1.99/D1=4.87	2.5/D1=3.06	-25.6/37.2
	Combined OARs	11.38	9.09	20.1
	MU	348	158	54.6
Breast 1	HI	0.31	0.18	41.9
	Target D95	42.04	47.69	-13.4
	Target mean	50.13	51.8	-3.3
	(Right)			
	Right Lung	5.88/V20=10.64	5/V20=8.40	14.9/21.1
	MU	180.9	185.8	-2.7
Breast 2	HI	0.43	0.21	51.2
	Target D95	38.61	47.54	-23.1
	Target mean	50.63	52.26	-3.2
	(Left)			
	Left Lung	5.63/V20=10.23%	4.35/V20=7.81%	22.7/23.7
	Heart	0.78	0.56	28.2
	LAD	2.85	1.86	34.7
	Combined OARs	4.2	3.23	23.1
	MU	191.9	189.2	1.4
Thoracic 1	HI	0.13	0.15	-15.4
	Target D95	39.68	38.97	1.8
	Target mean	42.34	42.58	-0.57
	Right Lung	23.73/V20=61.15	20.8/V20=54.43	12.3/10.99
	Left Lung	12.84/V20=27.43	11.22/V20=23.90	12.6/12.87
	Total Lung - GTV	16.39/V20=38.56	14.32/V20=33.91	12.6/12.06
	Atria	19.1/V25=29.53	14.47/V25=15.01	24.2/49.2
	Ventricles	9.92/V25=8.13	7.83/V25=2.38	21.1/70.7

		ORIG-3D	MCO-3D	% decrease
Thoracic 2	Spinal cord	15.19/D1=31.53	12.63/D1=33.35	16.9/-5.8
	Combined OARs	15.62	13.43	14
	MU	336.7	359.2	-6.7
	HI	0.1	0.12	-20
	Target D95	55.32	55.01	0.56
	Target mean	58.32	58.46	0.24
	(Esophagus) Right Lung	8.59/V20=16.82	7.73/V20=14.10	10/16.2
	Left Lung	9.41/V20=24.08	7.92/V20=19.52	15.8/18.9
	Total Lung - GTV	8.98/V20=20.26	7.82/V20=16.67	12.9/17.7
	Esophagus	32.34/V50=50.83	31.76/V50=50.4	1.8/.85
	Atria	23.17/V25=36.06	19.05/V25=24.92	17.8/30.9
	Ventricles	10.14/V25=3.63	9.87/V25=2.40	2.7/33.9
Abdomen 1	Spinal cord	1.69/D1=12.94	1.33/D1=5.32	21.3/58.9
	Combined OARs	11.68	10.5	10.1
	MU	488.6	359.9	26.3
	HI	0.06	0.07	-16.7
	Target D95	29.04	29.15	-0.38
	Target mean	30.14	30.29	-0.5
	(Pancreas) Small Bowel	11.76/D1=26.09	10.08/D1=23.57	14.3/9.7
	Large Bowel	7.22/D1=27.39	7.09/D1=25.79	1.8/5.8
	Spinal cord	4.38/D1=12.25	6.63/D1=18.78	-51.4/-53.3
	Left Kidney	2.68	2.74	-2.2
	Right Kidney	8.32	7.31	12.1
	Combined Kidneys	5.55/V10=17.78/V18=4.40	5.07/V10=10.34/V18=4.02	8.6/41.8/8.6
Abdomen 2	Stomach	3.35/D1=28.17/V40=0	3.62/D1=28.83/V40=0	-8.1/-2.3
	Combined OARs	5.33	4.9	8.1
	MU	529.9	405	23.6
	HI	0.05	0.08	-60
	Target D95	46.14	45	2.5
	Target mean	47.37	46.94	0.91
	(Pancreas) Small Bowel	2.98/D1=35.31	1.98/D1=20.71	33.6/41.3
	Large Bowel	3.31/D1=24.51	2.44/D1=20.8	26.3/15.1
	Spinal cord	13.81/D1=34.26	10.1/D1=31.24	26.9/8.8
	Esophagus	21.59/V35=43.41/V50=0	20.37/V35=41.45/V50=0	5.7/4.5/
	Stomach	23.72/D1=48.51/V40=36.89	21.05/D1=49.07/V40=29.04	11.3/-1.2/21.3
	Heart	13.59/V20=29.39	9.46/V20=18.9	30.4/35.7
Pelvis 1	Liver	15.11/V30=17.87	13.11/V30=11.08	13.2/38
	Combined OARs	10.41	8.78	15.7
	MU	259.5	254.9	1.8
	HI	0.04	0.04	0
	Target D95	65.83	64.74	1.7
	Target mean	67.33	65.89	2.1

		ORIG-3D	MCO-3D	% decrease
(Prostate Fossa)	Bladder	64.55	57.74	10.5
	Rectum	50.85/V55=38.01/V60=31.98	41.29/V55=21.75/V60=18.42	18.8/42.8/42.4
	Right Femur	31.63/V50=0	30.86/V50=0	2.4
	Left Femur	31.91/V50=.03	30.78/V50=0	3.5
	Combined OARs	44.05	39.95	9.3
	MU	218.5	252.5	-15.6
Pelvis 2	HI	0.05	0.09	-80
	Target D95	39.34	39.25	0.23
	Target mean	40.4	41.19	-2
(Bladder Bed)	Small bowel	14.2/D1=40.01	12.64/D1=40.26	11/- .62
	Rectum	27.92	25.94	7.1/7.1
	Left Femur	15.92/V50=0	11.71/V50=0	26.4
	Right Femur	27.85/V50=0	22.58/V50=0	18.9
	Combined OARs	14.67	12.73	13.2
	MU	273.9	224.6	18

For OARS, mean dose in Gy is the first value reported. For some of the organs, additional organ-specific dose-volume points follow, in Gy or percentage (for volume measurements). For the targets, D95, mean dose, and homogeneity index HI – as defined in the text – is reported.