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Original Article

Effect of dose prescription and block margin on small field treatment planning

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Abstract

Background and purpose: We evaluated the effect of block margin on small fields when point dose prescription (ICRU) or isodose line prescription (RTOG) formats are used.

Material and methods: A total of 11 clinical SBRT cases, one 4-field prostate case and 2 phantom cases using 0, 0.5 or 1 cm block margins were analysed. Integral dose and target coverage were compared using DVHs and isodose volumes for either isodose line prescription (100% Rx dose to 95% PTV volume) or isocenter point prescription (100% Rx dose to the isocenter) were calculated.

Results: Tight planning target margins using isodose line prescription leads to good target coverage but high dose heterogeneity with hot spots possibly exceeding 140% of the prescription dose for small target volumes. As block margin is increased, target coverage converges for the two methods but point dose prescriptions result in better dose homogeneity. For a given block margin, integral doses are consistently larger for isodose line prescription over point prescription, but are similar when block margins are adjusted to produce equal target coverage. As target size increases dose heterogeneity and integral dose differences disappear.

Conclusions: For small targets, the ICRU point prescription method can produce comparable PTV coverage to the isodose line prescription method with less dose heterogeneity and comparable integral dose. Reduction of hot spots in potentially normal tissue and reporting clarity makes this internationally recommended prescription standard preferable.

Keywords

DVH; ICRU prescription point; isodose line; PTV margin

INTRODUCTION

In 1993 and 1999 the International Commission on Radiation Units and Measurements (ICRU) published recommendations for prescribing dose.[1,2] The intent was to develop a systematic language for addressing 3D-planning and provide a simple, consistent standard for

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reporting radiation dose. From this have come definitions we have all become very familiar with, particularly for Intensity-modulated radiation therapy (IMRT) planning, including the gross, clinical and planning target volumes (GTV, CTV and PTV). The ICRU reference point for dose prescription was defined to be the isocenter, if beams are centered in the target. Otherwise, the prescription dose (100% isodose line) should go through the middle of the target volume. In our practice, we attempt to adhere to the ICRU prescription recommendations and also assure at least 95% prescription dose coverage of at least 95% of the PTV volume by adjusting the block margins. Recent Radiation Therapy Oncology Group (RTOG) protocols[3–5] require delivery of 100% of the prescription dose to 95% of the PTV volume, which means that doses must be scaled to an isodose line. Consequently, hot spots may be amplified in or around the target volume depending on the block margin in 3D-planning. This problem may be exacerbated as the target volumes diminish, as for the case of stereotactic body radiation therapy (SBRT) planning.

The issue of isodose line (which we will interchangeably call RTOG) versus point dose (ICRU) prescription has been addressed for 3D- and IMRT-planning by Kukolowicz and Mijnheer[6] and Yaparpalvi et al.[7] Kukolowicz observed that the ICRU dose coverage of the 95% PTV volume was generally within 3% of the RTOG volume coverage when full dose was prescribed to the 95% PTV volume. Yaparpalvi compared PTV coverage versus dose prescription between ICRU, RTOG and the mean or median dose normalisation of the PTV dose for 3D- and IMRT-planning. They found that the mean dose to the PTV correlated well with the ICRU reference point dose, as did Kukolowicz. Das et al.[8] conducted a study of dose variation in IMRT planning in a five-institution study, including 803 patients, finding IMRT dose heterogeneity results in large excursions from the prescribed dose, complicating the determination of the reportable dose. From another perspective, Hess et al.[9] discussed the problems of changing from prescription to a minimum isodose line to isocenter prescription method. From the point of view that for the latter method the mean target doses will probably be lower and more homogeneously distributed than the physicians are used to delivering, it may be useful to have physicians reconsider their prescription doses.

One of the reported benefits of SBRT is to achieve lower integral doses. In their study, Molinelli et al.[10] reviewed the effects of block margin on integral liver dose in SBRT treatment of 14 patients with liver metastases. They used margins ranging from 0.0 to 1.0 cm and 10 fields per plan, using an optimisation routine to adjust beam angles and weights to maximise liver sparing. Doses were all prescribed to the 65% isodose line. They observed reduction in isodose volume concomitant to increased hot spot dose (described as dose escalation) as PTV margin was reduced.

In this paper, we compared the RTOG and ICRU dose prescription approaches to consider how choice of prescription method affects integral dose, hot spot dose and PTV volume coverage as a function of block margin, particularly for small targets and small fields. For our study, we used a number of previously treated clinical cases, including one prostate case and 11 SBRT cases. We also generated two simple phantom cases in which either a 2 cm or 8 cm diameter sphere formed the PTV volume. The cases were selected to provide a broad range of PTV volumes (3.4–290 cm^3). Resultant target coverage and corresponding integral dose as a function of prescription method and blocking were reviewed.

METHODS AND MATERIALS

Pinnacle (V8.0m) was used for planning. Two phantom case studies were generated, consisting of either a 2 cm or 8 cm diameter sphere, centred in a $30 \times 30 \times 30$ cm^3 water-equivalent density phantom was created in Pinnacle and planned using four equally weighted 6 MV fields. Clinical cases included a single 4-field prostate plan and 11 heterogeneity-corrected SBRT cases, all of which employed 6 MV fields. All of the clinical plans maintained the

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beam arrangement and weighting used for the actual treatments and were recalculated for each block configuration using a $2 \times 2 \times 2$ mm^3 dose grid, and were recalculated using the original CT dataset.

Three plans were generated; one for each blocked field arrangement. The PTV block margins we used were 0 cm, 0.5 cm and 1.0 cm, which are typical block margins used in our clinic. For the case of ICRU prescription, the isocenter was used for dose normalisation. We analysed PTV coverage as a function of block margin and recorded the fractional volumes contained in each isodose level in 10% steps. For comparison, we took each of these three plans and applied the RTOG prescription criteria by renormalising the doses using the isodose line that resulted in 95% of the PTV receiving 100% of the prescription dose. The effects of prescription differences on relative PTV coverage, hot spot magnitude and on the amount of normal tissue volume contained within different isodose levels are reviewed.

RESULTS AND DISCUSSION

The PTV volumes for each case are listed in Table 1 and ranged from 3.4 to 290 cm^3. Dose–volume histograms (DVH) were generated for each block margin and each prescription method (point or isodose line). Results for the phantom study cases are shown in Figures 1 and 2 (8 cm and 2 cm diameter spheres, respectively). Figures 1a and 2a compare PTV coverage differences, while Figures 1b and 2b plot tissue volumes contained in each isodose level. In these figures, solid lines are used for ICRU point dose prescription and dashed lines for RTOG isodose prescription. To accomplish the latter, we simply rescaled the doses by the isodose line, which results in 95% of the PTV volume receiving the prescription dose. Those prescription isodose lines are included in the figure caption insets and also listed in Table 1. To make it easier to see differences in PTV coverage in this and the following figures, we added a vertical marker line at 95% dose.

For the largest PTV volume, represented by the 8 cm diameter PTV, we see (Figure 1a) that 0.5 cm margin is sufficient to yield comparable target coverage, regardless of prescription method. If no block margin, was used the 89% isodose line would have been needed for the RTOG method, resulting in a significant volume receiving more than 110% of the target dose with consequent increase in the volume of tissue receiving lower doses (Figure 1b).

At the other end of the volume range, Figure 2 displays the small PTV result (2 cm diameter). We see, similar to Figure 1, that 0.5 to 1.0 cm block margin is sufficient to achieve uniform

Table 1. *Prescription isodose to deliver 100% dose to 95% PTV as a function of block margin*

	PTV volume (cm^3)	**0 cm**	**0.5 cm**	**1.0 cm**
Case		Rx %	Rx %	Rx %
SBRT 1	14.7	75	82	86
SBRT 2	38.4	62.5	78	87
SBRT 3	45.3	72	91.5	95
SBRT 4	48.9	79	94	97
SBRT 5	49.7	71.8	81.5	90
SBRT 6	74.9	81	93	98
SBRT 7	110.5	76	88	93
SBRT 8	140.7	69	82	88
SBRT 9	173.2	82	94	98
SBRT 10	188.8	88.5	95.2	97
SBRT 11	199.1	68	80	83
Prostate	252.7	68	90	96.5
2cm	3.4	76	96.7	99
8cm	290.1	89	96	97.5

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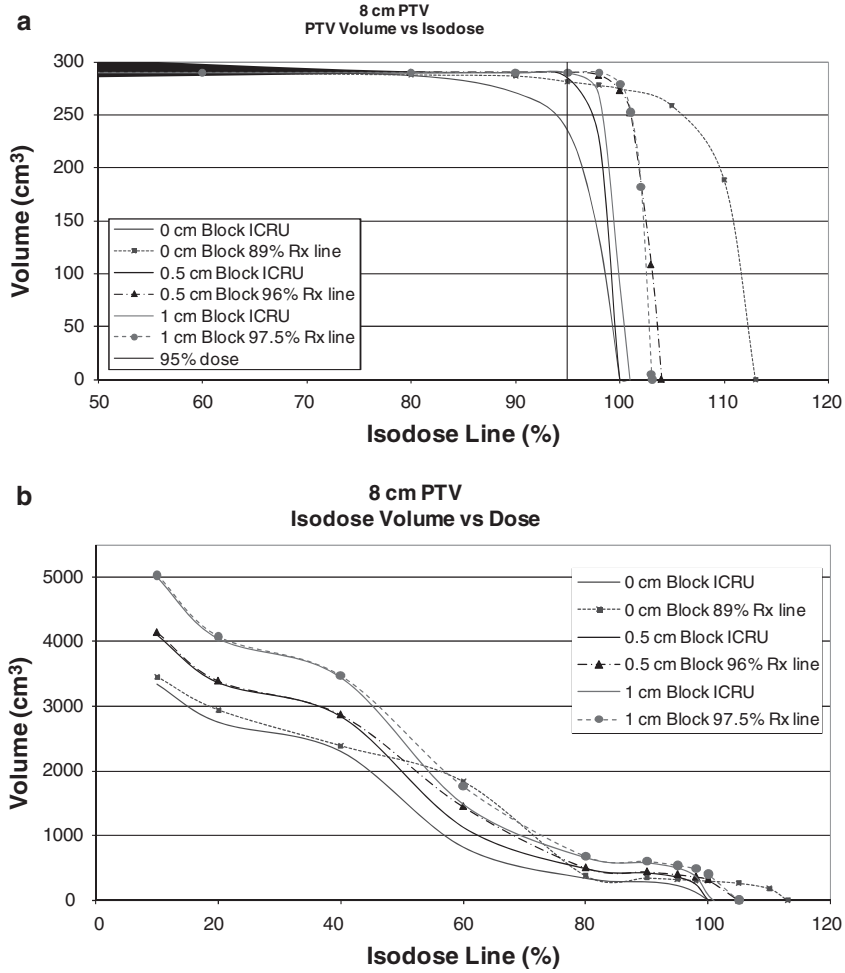

Figure 1. (a) Distribution of absolute volume as a function of relative dose percentage to an 8 cm diameter PTV. Solid lines represent ICRU normalised doses for 0.0, 0.5 and 1.0 cm block margins. Dashed lines correspond to the same margins for RTOG normalised doses. Prescription isodose lines used for the RTOG data are listed in the caption insert. (b) The same comparison, but for integral dose to the phantom.

PTV coverage for either prescription type. If no margin is used, however, the 76% isodose line would have to be used to satisfy the RTOG criteria resulting in as much as a 130% hot spot dose. The effect on integral dose of prescription method (Figure 2b) is not as dramatic as for the larger target, though, with similar volumes irradiated when 0.5 or 1.0 cm margins were used. For the no margin case integral doses resulting from point dose prescription are lower than when prescription is to an isodose line.

A mid-volume (110.5 cm^3) SBRT case is shown in Figure 3. The PTV coverage as a function of prescription and block margin follows the same trend; that is, as the block margin increases from 0.0 to 1.0 cm coverage of the target using ICRU point dose prescription approaches that for the RTOG isodose scaling method. The no margin isodose volume distribution for isodose line normalisation is approximately the same as for the 0.5 cm margin point dose case. This general trend is observed for all the SBRT cases.

In general, we have observed a simple correlation between PTV target volume and the block margin needed for the ICRU cases to achieve comparable coverage to isodose normalised plans. This is shown in Figure 4. For all

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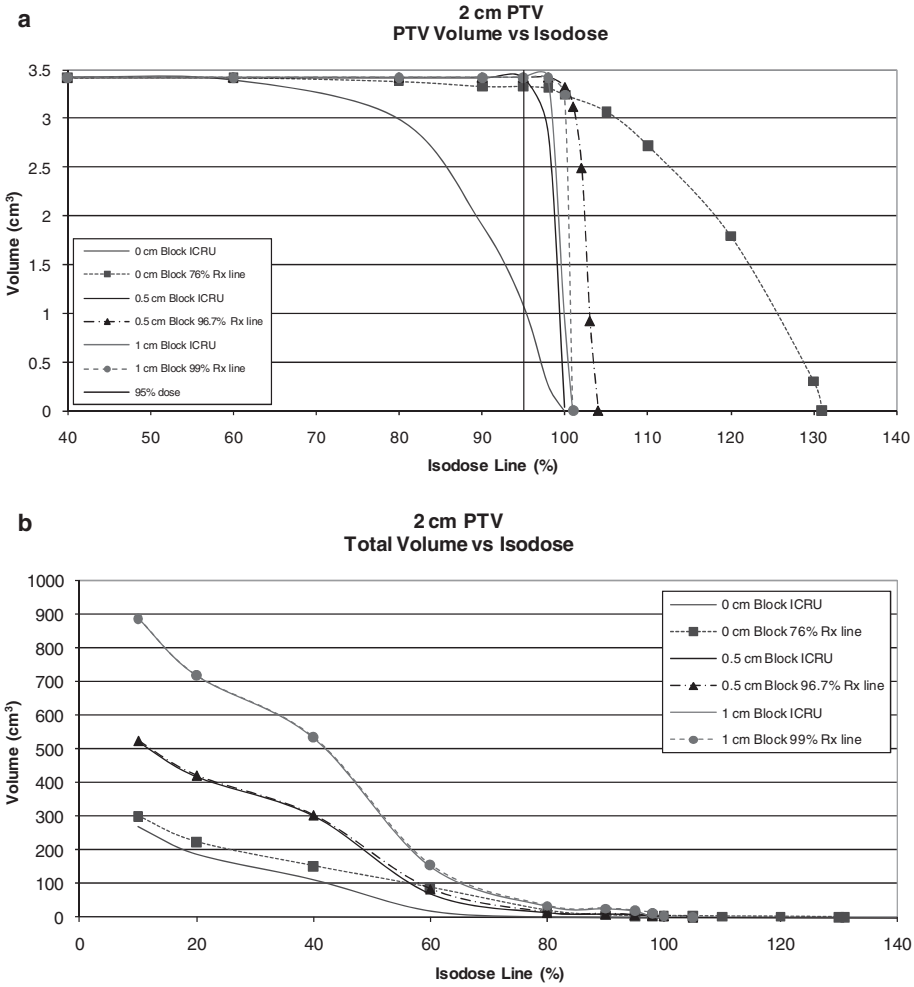

Figure 2. (a) Distribution of absolute volume as a function of relative dose percentage to a 2 cm diameter PTV. Solid lines represent ICRU normalised doses for 0.0, 0.5 and 1.0 cm block margins. Dashed lines correspond to the same margins for RTOG normalised doses. Prescription isodose lines used for the RTOG data are listed in the caption insert. (b) The same comparison, but for integral dose to the phantom.

cases we found the percentage PTV volume that received at least 95% of the prescription dose and plotted that as a function of total PTV volume and block margin. The general trend of the data shows that with increasing PTV volume, block margin becomes less important, and almost vanishes by about 350 cm^3, as the percentage of covered volume predominates. For smaller, SBRT volumes, there is much more heterogeneity in the coverage due to target asymmetry requiring considerably larger margins to achieve adequate PTV coverage.

The impact of dose prescription method on integral dose is summarised in Figure 5, where we compare ratios of isodose volumes for RTOG isodose normalised plans to ICRU point dose normalised plans. Results in Figures 5a–c correspond to 0, 0.5 or 1.0 cm block margins, respectively. In each case, we plot the ratio of volumes contained within each isodose level (10–80%) as a function of the isodose prescription line that was used for RTOG normalisation (Table 1). For reference, recall that the isodose prescription lines are strongly correlated with PTV volume. Lower

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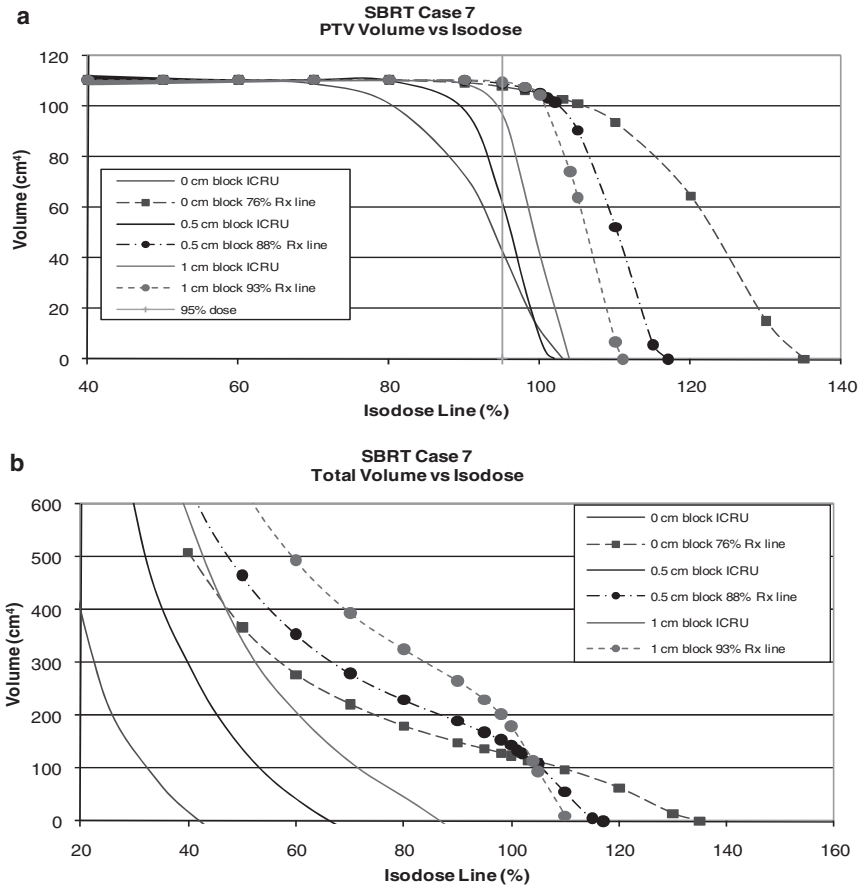

Figure 3. (a) Distribution of absolute volume as a function of relative dose percentage to a 110 cm^3 SBRT PTV (Case 7). Solid lines represent ICRU normalised doses for 0.0, 0.5 and 1.0 cm block margins. Dashed lines correspond to the same margins for RTOG normalised doses. Prescription isodose lines used for the RTOG data are listed in the caption insert. (b) The same comparison, but for integral dose to the phantom.

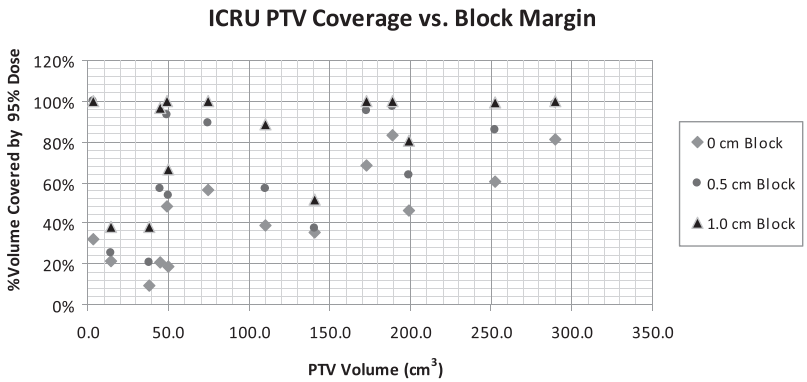

Figure 4. Plot of percentage PTV volume covered by 95% of the prescription dose as a function of block margin for all of the ICRU normalised cases. Trend lines are drawn to help guide the eye.

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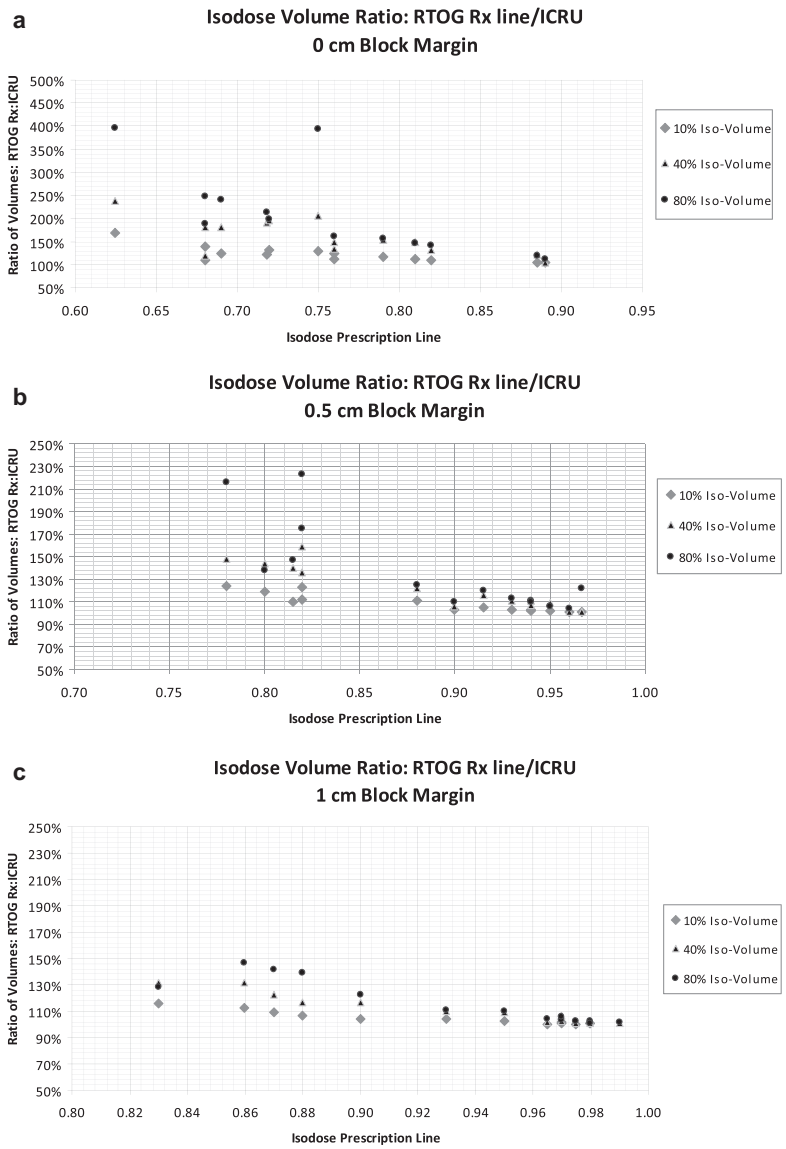

Figure 5. Ratio of isodose volumes for RTOG dose normalisation to that for ICRU normalisation. Data are plotted as a function of the prescription isodose used for the RTOG cases. (a) Volume ratios for 0.0 cm block margins; (b) volume ratios for 0.5 cm block margins; (c) volume ratios for 1.0 cm block margins.

values of prescription lines correspond to smaller PTVs. The general trend of the data shows that, though there were a few outliers, as the magnitude of the prescription isodoses approach unity, so do the volume ratios. Our results show that the integral dose differences are only observed for small target volumes. These differences increase significantly as the PTV target volumes shrink due to the lower and lower prescription isodoses needed to achieve coverage with RTOG-type prescriptions. The typical range of SBRT dose prescription lines are 80–90%.

As a last point, we calculated the same integral dose ratios as in Figure 5 for our sample of 11 SBRT cases, but instead of comparing prescription methods with the same margins we used the no-margin RTOG isodose line prescription plans and compared them against

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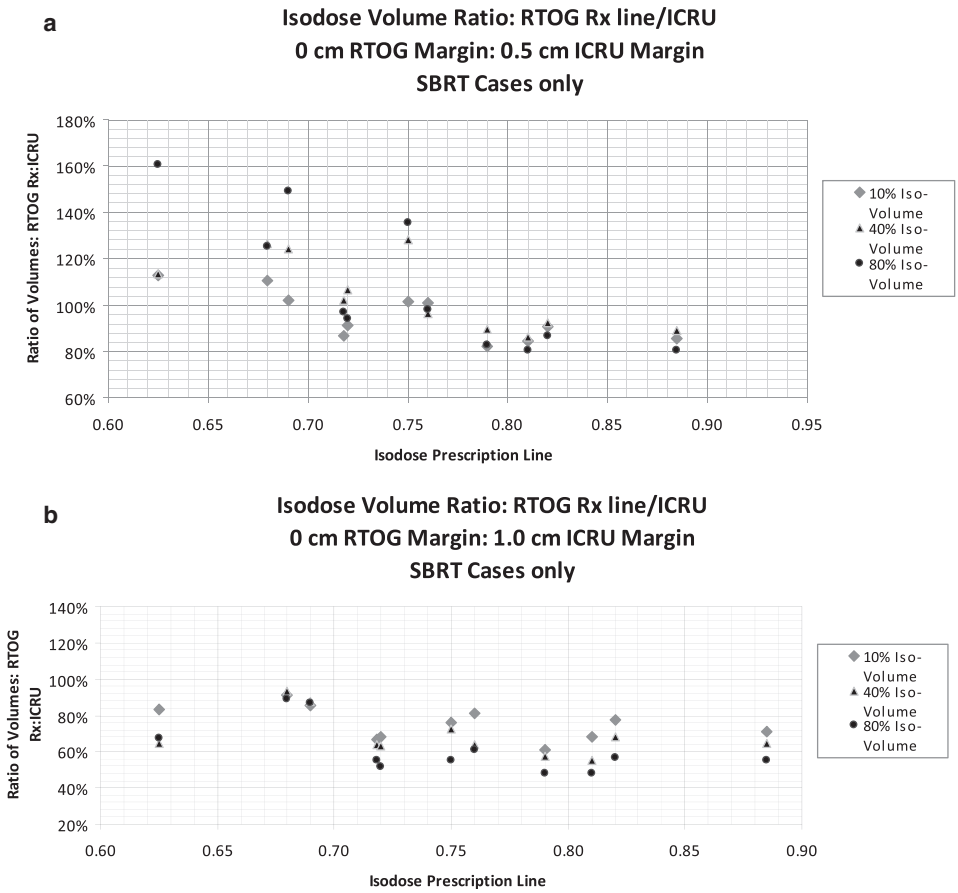

Figure 6. Ratio of isodose volumes for RTOG dose normalisation for 11 SBRT cases only using 0.0 cm block margins to that for ICRU normalisation using either (a) 0.5 cm block margins, or (b) 1.0 cm block margins. Data are plotted as a function of the prescription isodose used for the RTOG cases.

either 0.5 or 1.0 cm margin ICRU point dose normalised plans. This more closely matches clinical planning objectives in our department, where either no margin, isodose normalised prescriptions or ICRU point prescriptions accompanied by sufficient margin to cover 95% volume with at least 95% dose are used.

It is interesting to see that the integral dose ratios for small targets are much more comparable when compared in this way. For the 0.5 cm margin case (Figure 6a), the point prescription integral doses are less than those for the RTOG case, but only by 10–20% through most of the volume range. When we use 1.0 cm margin (Figure 6b), the integral doses become better for isodose line prescriptions by almost the same amount. The obvious conclusion is that carefully selected block margins, between 0.5 and 1.0 cm, would result in a complete wash of integral dose differences between the two prescribing methods. For small targets then, ICRU point dose prescriptions, with adequate block margins in the range of 0.5 to 1.0 cm will result in identical integral doses, but with more homogeneous target coverage compared with RTOG isodose line prescriptions. Target dose heterogeneity differences are reduced when similar block margins are used for isodose line prescriptions as for the ICRU case. For target diameters greater than about 8 cm, neither block margin nor prescription method results in integral dose or dose heterogeneity differences between prescription methods.

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CONCLUSIONS

Previously published literature has stressed the importance of prescribing, recording and reporting radiation therapy treatment doses and treatment volumes clearly and unambiguously so that they could be easily tracked worldwide. One of the recommendations of ICRU 50 and its supplement ICRU 62 is to prescribe to a point inside the planning target volume (ICRU reference point) instead of prescribing to the periphery of the PTV (an isodose line). A quantitative comparison between point prescription methods and isodose line prescription methods for small field dosimetry has not yet been reported in the literature. Our study compared these two methods with regards the effect of block margin on small target coverage and integral dose.

Our results are clinically relevant; PTV coverage can be achieved using the ICRU point prescription method without resulting in the large hotspots that are seen using the RTOG isodose line prescription method. This is achieved by using a large enough block margin. Our results show that the smaller the PTV, the larger the block margin needs to be to match the PTV coverage using both prescription methods. In other words, as the PTV gets larger, block margin becomes less important for prescription. This is why we have concentrated this paper on small field prescription where block margin is, or could be clinically relevant.

We have found that for small targets typical of SBRT, the ICRU point prescription approach results in homogenous target doses when block margins are of the order of 0.5 to 1.0 cm, consistent with our clinical goal of achieving at least 95% dose to 95% PTV volume. The RTOG isodose line prescription is used to force 100% dose to at least 95% PTV volume, but results in increased dose heterogeneity with decreasing target size. As Molinelli et al.[10] pointed out, integral dose is indeed reduced in SBRT planning as the margin is reduced but at the cost of this increased target dose heterogeneity. When we compare integral doses for optimised block margins that yield similar PTV coverage, however, either prescription method results in the same dose–volume dependence. The main difference between point dose and isodose line prescription becomes PTV dose heterogeneity, which becomes more pronounced with decreasing target size, and which may or may not be advantageous. If normal tissues are included in target volumes, then high dose regions may not be optimal. In retrospect, ICRU Report 50 provides a clear and unambiguous method for specifying and reporting doses that minimises patient-to-patient variation, improving the chance of unbiased outcome analyses. If the same clinical end can be achieved with homogeneous dose distributions, and the same integral dose as for isodose line prescription, then the benefits of adhering to such a standard are clear.

A more recent report, ICRU 83,[11] recommends standards for recording and reporting doses in for IMRT treatment planning. Our future study includes repeating our study and evaluating IMRT treatment prescription and reporting methods.

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