Incorporating high dose inhomogeneity into SBRT treatment planning

Introduction: By encouraging greater dose inhomogeneity in the PTV, Stereotactic Body Radiation Therapy (SBRT) allows higher doses to be delivered to the target. For safer dose delivery, however, besides the strict dose constraints by Radiation Treatment Oncology Group (RTOG) protocols, the more specified considerations are necessary. This work aims to incorporate the high dose inhomogeneity using more specific localized information inside the PTV into the lung SBRT plan by the total-variation (TV) minimization with TFOCS\(^5\), referring to the dose constraints in RTOG 0915\(^5\).

Methods: Table 1 specifies the strict dose constraints for the lung SBRT plan by RTOG 0915, where HDS regulates the safety in the healthy tissue around the PTV, and IDS indicates the stiff fall-off gradient outside the PTV. The second dose constraint in PTV informs the degree of dose inhomogeneity into the target by the ratio of the reference dose to the maximum dose (0.6-0.9).

In this work, two approaches are proposed to achieve high dose inhomogeneity. First, we implicitly can reduce dose uniformity in PTV by increasing the error tolerance (\(\varepsilon_{PTV}\)) and dose distribution (\(d_{PTV}\)) in Eq.(1), which is based on the TV form to reduce the complexity of the fluence-map. For high dose inhomogeneity, however, the model in Eq.(1) without more specific localized information in the target can impair the healthy tissue inside the PTV and can make the maximum dose (hot spot) located far from the center of the PTV. Hence, the second step is to add specific localized information by introducing the structure (PTV\(^{'}\)), located at 5 mm to 1 cm inside the PTV as presented in Fig.1 and Eq.(2), where it is \(k_{PTV} > k_{Margin}\), \(d_{PTV} > d_{Margin}\) (\(n_i\) : number of voxels of structure \(i\)). It implies that it prescribes the high dose inhomogeneity into PTV only, not entire PTV. By appropriately controlling the values in Eq(2), the dose inhomogeneity can be achieved inside the PTV in secure fashion.

For the validation, the lung data (34cc, \(D_{ref} = 50\)Gy) was employed at 15 beams (20x20 beamlets with 5mm resolution). The structure (PTV\(^{'}\)) introduced inside the PTV has the volume of 12.5 cc. To meet the IDS, all tissues up to 2 cm away from the PTV were involved as a tuning structure. For all plans, the tuning structure is maneuvered to have the same fall-off gradient outside the PTV for the fair comparisons. This work designs three different plans as shown in Table 2, where case 3 is perceived as the proposed model.

Results and Discussions: The resultant plans were acquired at 60 segments. Fig.2 with DVHs indicates that the plan from the proposed model (case 3) at the marginal side of the PTV has as low dose of radiation as that of homogeneous plan (case 1), while the higher dose inhomogeneity is guaranteed inside PTV\(^{'}\) with the similar maximum dose to that of inhomogeneous plan (case 2). Additionally, the proposed model helps the hot spot be located nearby the center of the PTV as shown in Fig.3 due to the specific localized information. Statistically, the plan of case 3 results in the hot spots located inside PTV\(^{'}\) and GTV at 100%, while the case 2 made at 92.3% and 80%, respectively.

Table 3 gives the numerical information of dose constraints, proving that all plans obey the dose requirements in RTOG 0915. Importantly, however, increasing the dose inhomogeneity without specific local information (case 2) can more harm the healthy tissue as it increases HDS from 0.15% to 0.52%. The proposed model successfully lowers HDS to the that of homogeneous plan (0.52% \(\rightarrow\) 0.18%).

The benefits from the proposed model for the higher dose delivery to the target can be summarized in four points. First, the proposed method can be easily implemented by slightly modifying the model as in Eq.(2) using the TV solver (TFOCS). Second, it can preserve the marginal side of the PTV at the similar level of the IDS: (Max. dose at any point 2cm or greater away from PTV) \(\leq 0.58(D_{max})\).

Conclusion: The proposed method using specific localized information inside the PTV can safely and effectively deliver higher doses to the target and lead to improved local control in SBRT plan.

Reference:
[5] RTOG 0915

- **Table 1**: Dose constraints in RTOG 0915 to be considered for lung SBRT planning
- **Table 2**: Design of the three cases with different characteristic
- **Table 3**: The results of the plans from three conditions, referring to the dose requirements in RTOG 0915, at 60 segments

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\[ \text{Reference:} \]
\[ \text{[1] Timmerman et al, Journal of Clinical Oncology, 2007;25:947-952} \]
\[ \text{[2] Potter et al, Radiotherapy and Oncology, 2007;85: 260-266} \]
\[ \text{[3] Zhu et al, PMB, 2008;53:6653-6672} \]
\[ \text{[5] RTOG 0915} \]