Optimization rotating shield brachytherapy treatment plan under treatment time budget

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Purpose: To compute an optimized brachytherapy treatment plan under a given treatment time budget, to greatly reduce treatment time of rotating shield brachytherapy (RSBT) for cervical cancer without compromising plan quality, and to directly optimize D_{90} to further improve plan quality.

Methods: In the RSBT treatment planning system, we use single shield with 45° emission angle and radiation source ^{169}Yb. We introduce a time budget constraint in the treatment planning and model the problem as a quadratic optimization which is solved by CPLEX. We investigate the tradeoff between treatment time and plan quality. We further introduce another novel second stage planning to achieve the following goals: (1) directly optimize D_{90}; (2) explicitly constrain the scaling factor to be 1. The first model provides guidance for defining a hottest 90% region in high-risk clinical target volume (HR-CTV) and hottest 2 cm^3 regions in organ at risks (OAR), and the second planning will directly maximize D_{90} under the tolerance constraints for OARs and treatment time constraint.

Results: We validate our algorithms via experiments on 5 patient cases. The results show that on average, when we reduce the delivery time from 45.85 min to 37.10 min and 28.14 min, the D_{90} will decrease from 88.12 Gy to 86.10 Gy and 81.98 Gy correspondingly. The results also show that on average, the second planning can further improve the D90 from 88.12 Gy to 90.47 Gy.

Conclusion: This work shows that significant reduction in treatment time is possible without compromising the quality of treatment plan. By introducing a second stage planning, the D_{90} can be further improved.

Keywords: Brachytherapy, treatment planning optimization, D_{90} optimization

Innovation: The novelties of this study include: 1) we consider explicitly the delivery time budget and find an optimized treatment plan under this budget (first stage planning); 2) We further introduce a second stage planning which is based on the first stage planning. When the first stage planning does not find best treatment plan, the second stage planning can find one closer to the best treatment plan. When the first model finds the best treatment plan, the second stage model can serve as a double-checking role.

Key Results: The experiments are conducted on 5 patient cases. The tradeoff between delivery time reduction and plan quality is shown in Figure 1-2 for the case 2 and case 5 respectively. In Figure 3, we demonstrate the D_{90} improvements for each case with 5 different trials (the D_{90} obtained in second stage planning minus the D_{90} obtained in the first stage planning). We present the dose map and DVH dose escalation under different time budgets for case 1 using the first stage planning in Figure 4-7. We present the dose map and DVH dose escalation for case 2 using first stage planning and second stage planning in Figure 8-11. We present the quantitative results averaged over 5 cases in Table 1.

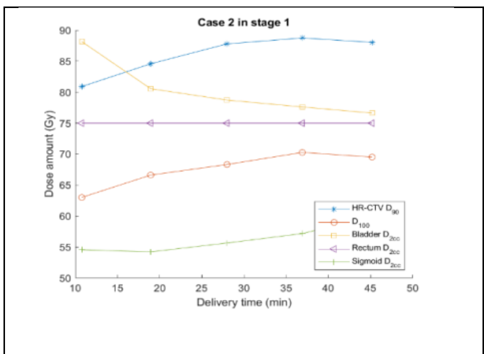

Figure 1: Dose variation and delivery time variation using first stage model.

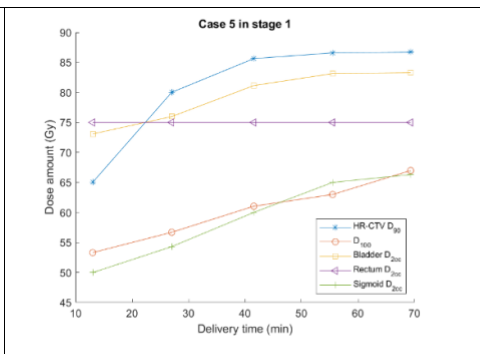

Figure 2: Dose variation and delivery time variation using first stage model.

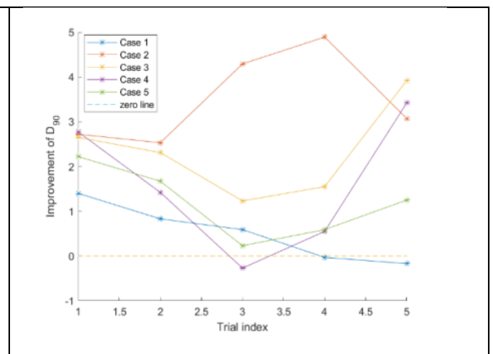

Figure 3: D_{90} improvement using second stage model. Compared with D90 obtained using first stage model.

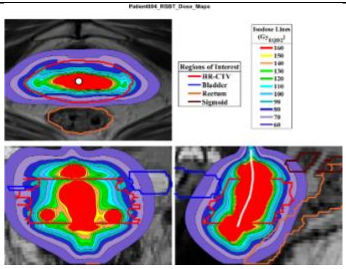

Figure 4: Dose map of case 1 with delivery time 39.13 min, first stage model used.

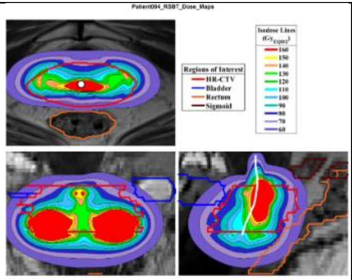

Figure 6: Dose map of case 1 with delivery time 17.66 min, first stage model used.

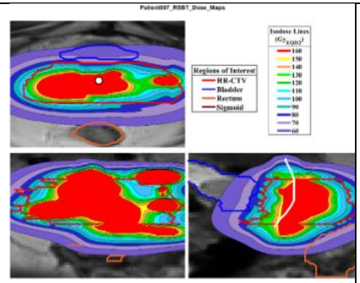

Figure 8: Dose map of case 2, first stage model used.

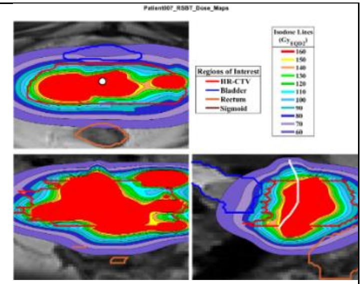

Figure 9: Dose map of case 2, second stage model used.

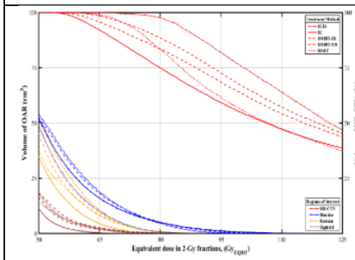

Figure 5: DVH dose escalation of case 1 with delivery time 39.13 min, first stage model used

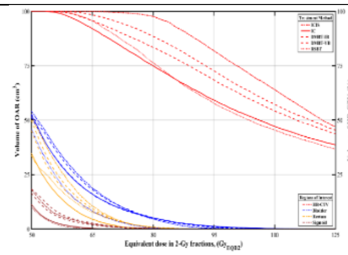

Figure 7: DVH dose escalation of case 1 with delivery time 17.66 min, first stage model used.

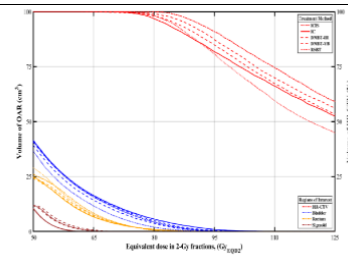

Figure 10: DVH dose escalation of case 2, first stage model used.

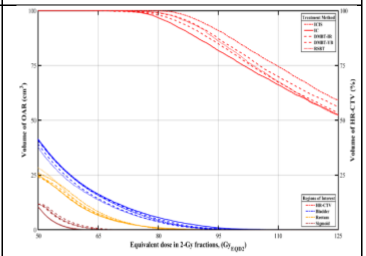

Figure 11: DVH dose escalation of case 2, second stage model used.

Treatment time (min)	45.85±13.49	37.10±10.66	28.14±7.91	19.02±4.99	10.16±2.00
D_{90} (Gy)	88.12±8.19	86.10±6.18	81.98±6.79	75.20±8.75	64.14±10.50
D_{100} (Gy)	67.13±7.14	64.46±6.04	60.52±5.39	56.58±5.99	52.41±6.41
D_{2cc} bladder (Gy)	81.48±5.87	81.29±5.81	80.66±5.23	80.38±5.69	79.45±8.93
D_{2cc} rectum (Gy)	70.28±6.69	71.67±5.86	72.90±4.69	73.91±2.44	73.27±3.86
D_{2cc} sigmoid (Gy)	67.47±5.83	65.99±6.85	63.86±7.68	61.23±9.15	58.30±9.02

Table 1: Average performance over 5 patient cases. Different trials have different delivery time budget.