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Impact of Fluence-Based Constraints on VMAT Plan Optimization

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INTRODUCTION

Volumetric-modulated arc therapy (VMAT) plan optimization remains a challenging problem due to its non-convex character and the large dimensionality of the solution space. Commonly, the problem is split in three steps: 1) ideal fluence optimization 2) arc sequencing and 3) direct aperture optimization (DAO). Traditionally, the optimized fluence is only used to generate a good initial solution. Additional utilization through fluence-based regularization in the DAO cost function may yield further benefits. Here we investigate the benefits of such regularizations in terms of organ at risk dose and plan complexity, which is especially relevant for MR-linac implementations.

METHODS

Figure 1 illustrates how the trade-off index is defined. On a set of axes representing two normalized plan quality metrics (here the normalized average dose to rectum and bladder D and the normalized plan complexity E) we draw the reference plan (no penalty) and a plan generated with the inclusion of a regularization penalty (plans (E1,D1) and (E2,D2)). A plan that falls in the “Pure gain” region indicates that the constraint improves both metrics. A plan falls in the “Pure loss” region when the addition of a constraint deteriorates both metrics. The TOI is defined as:

$$\mathrm{TOI} = \begin{cases} 0, & \text{pure gain region} \\ 1, & \text{pure loss region} \\ \sin(\theta), & \text{anywhere else} \end{cases}$$

A smaller TOI (closer to 0) indicates a more favorable trade-off between OAR dose and complexity. Figure 2 shows the comparison between multiple constraints in terms of the TOI index. Each boxplot shows multiple TOI values calculated for sample plans obtained using different regularization weights. The plot reveals a range of different average values for different constraints with the quadratic fluence achieving the best score. The plot also highlights that even within a given constraint, different regularization weight values can significantly alter its added benefit to the generated plans.

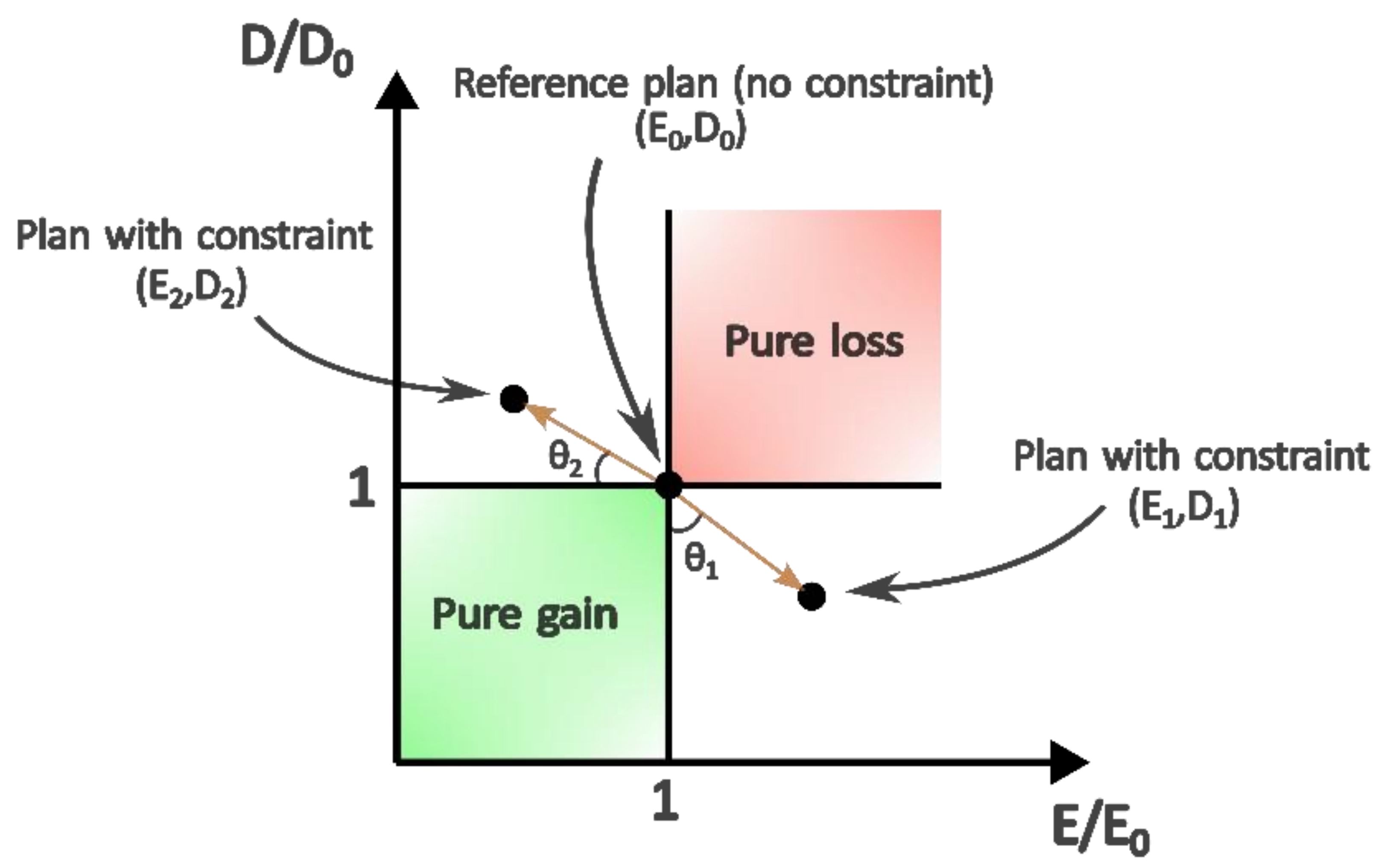

Figure 1: Illustration of the TOI index and its definition

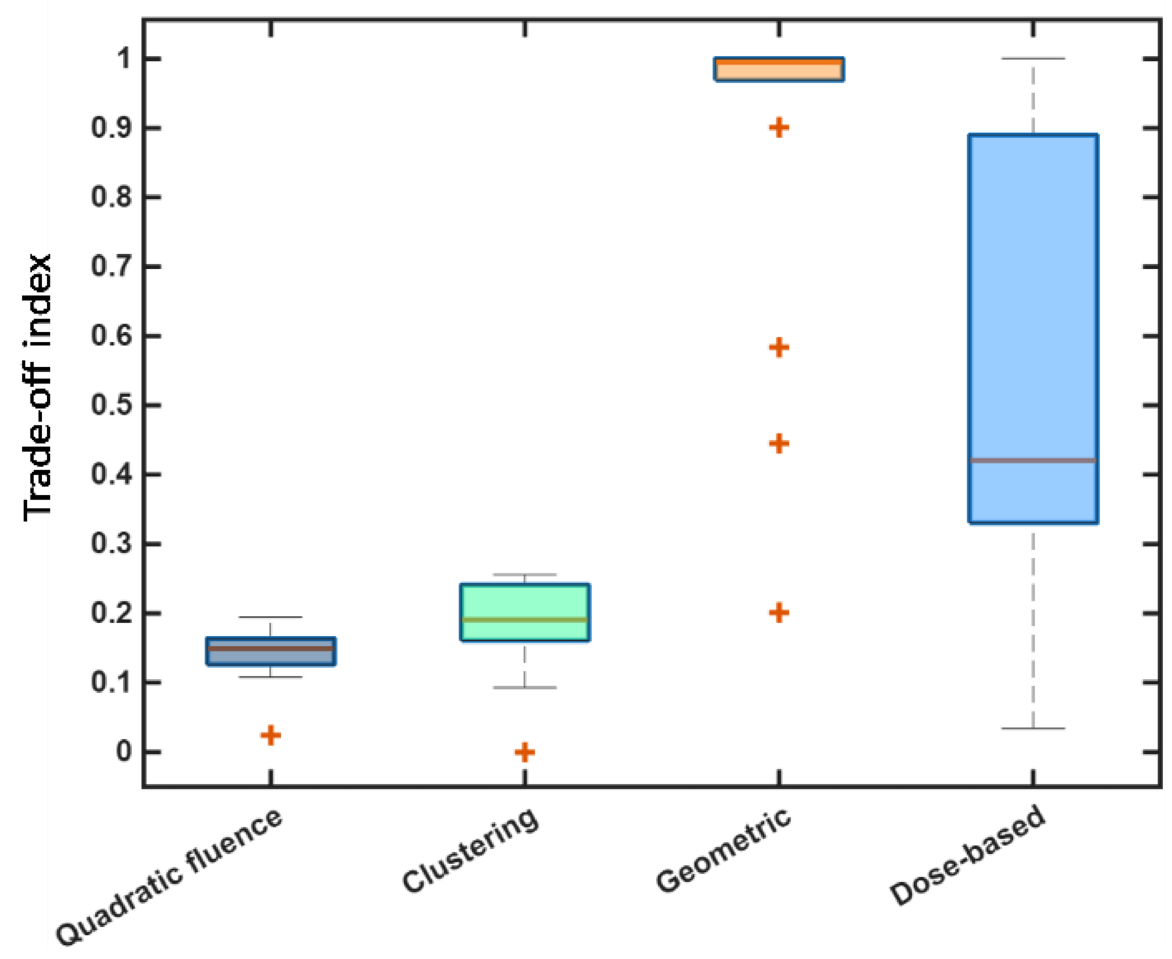

Figure 2: Comparison of different regularization constraints using the TOI metric.

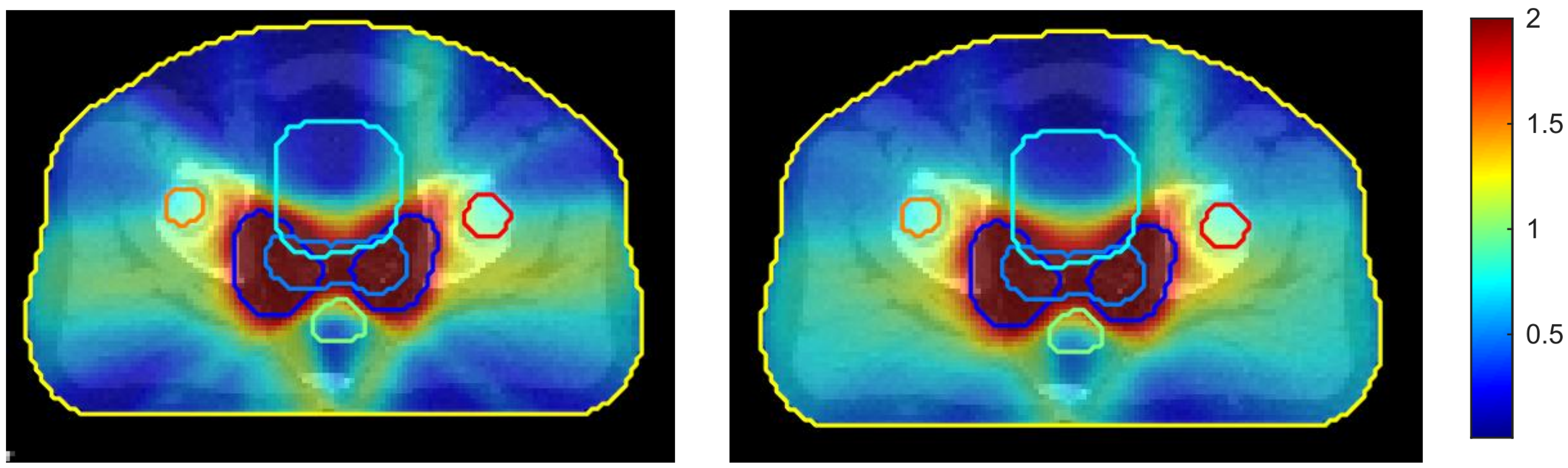

Figure 3: Dose distribution of a reference plan without constraint (left) and a plan using a quadratic fluence constraint (right). We observe that the dose gradients become less sharp after the introduction of the constraint. At the same time, the plan complexity reduces from 443 MU/Gy in the reference plan to 352 MU/Gy.

CONCLUSION

This study introduced a method to quantify the benefit of adding a given penalty term to the direct aperture optimization problem in VMAT planning. Due to the large dimensionality and multiple competing optimization quantities, assessing the effect of added constraints can be cumbersome. To that end we introduced the trade-off index (TOI). Using TOI, we compared four different types of constraints.

More generally, we provide a standardized workflow to evaluate the benefit of different regularizations in the DAO optimization cost function. This can lead to straightforward decisions on the efficacy of added plan optimization constraints.