Transferring Beam Navigation Behavior from Human to Robot: An Evidence Driven Decision Making Model for Liver SBRT

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JULY 12–16 2020 VIRTUAL
JOINT AAPM | COMP MEETING
EASTERN TIME [GMT-4]

INTRODUCTION

Stereotactic body radiation therapy (SBRT) for liver cancer has shown promising therapeutic effect. Dose escalation relies not only on the precise treatment provided by image-guided radiation therapy (IGRT) but also high dose gradient formed around the treatment volume to spare functional liver tissue. Liver SBRT treatment planning has therefore been a challenging task. Intermediate-to-low isodose lines such as 20Gy has been primary sparing endpoint for functional liver tissue, whereas in 50Gy/5 fractions treatment regimen it links to 40% isodose line. Similar to lung treatment planning, beam angle selection plays an important role in dosimetry performance due to the highly malleable nature of such isodose line. Liver lesions often present as spherical shape and planner often struggles with liver sparing rather than target coverage. Human planner's reasoning for choices of beam setting selection is inexplicitly reflected in the plan. In this study, we developed an evidence driven model to capture and transfer human's reasoning and automatically generate optimal beam setting for liver SBRT.

AIM

To develop decision making model to learn human planner's beam navigation behavior for beam angle/arc angle selection for liver SBRT.

METHOD

A total of 27 liver SBRT/HIGRT patients (10 IMRT, 17 VMAT/DCA) were included in this study. A dosimetric budget index was defined for each beam angle/control point considering the body as well the liver tissue

Formalism:

The dosimetric budged index is composed of two terms, namely body and liver, as presented the first two terms in Equation 1. It estimates how much entrance dose is deposited given a candidate beam angle. The beam selection solution is the minimization problem formulated as in Equation 1 to yield beam setting parameters p, as beam angles for IMRT or start and terminal control point angle in VMAT.

$$\min_{p}[\max(0, B_{body} - t_{body}) + a \cdot \max(0, B_{liver} - t_{liver}) + b \cdot f_{beam}] \quad \text{(Eq.1)}$$

where B_{body} and B_{liver} are body and liver dosimetric budget, respectively; t_{body}, t_{liver}, a and b are hyperparameters tuned in nested cross validation; f_{beam} is beam span penalty function defined separated for IMRT and VMAT. For IMRT,

$$f_{beam} = \max[\max(\,20 - \min(|b_i - b_j|), 0)^2, c \cdot \max(5 - \min(|180 + b_i - b_j|), 0)^2] \text{ (Eq.2)}$$

subject to $b_i, b_i \in \{b_1, \ldots, b_n\}$; c is hyperparameter.

For VMAT,

$$f_{beam} = [\max((180 - |c_s - c_t|), 0)]^2 \quad \text{(Eq.3)}$$

where c_s is the start control point angle and c_t is the terminal control point angle.

Study Design:

Leave-one-out validation was exercised on all 27 case while hyperparameters in the loss function was tuned in nested cross validation. To compare the efficacy of the model, an evidence guided plan (EG-plan) was generated using automatically generated beam setting together with original optimization constraints in the clinical plan. EG-plan was normalized to the same PTV V100% as clinical plan. Dosimetric endpoints including PTV D98%, D2%, liver V20Gy and total MU were compared between two plan groups. Wilcoxon Signed-Rank test was performed with the null hypothesis that no difference exists between two groups.

RESULTS

Beam setting prediction is instantaneous. Mean PTV D98% was 91.3% and 91.3% (p=0.164), while mean PTV D2% was 107.9% and 108.1% (p=0.566) for clinical plan and EG-plan respectively. Liver V20Gy showed no significant difference (p=0.590) with 23.3% for clinical plan and 23.4% for EG-plan. Total MU is comparable (0.256) between clinical plan (2389.6) and EG-plan (2319.6).

Beam Setting Comparison:

Evidence guided beam setting prediction is shown Figure 1. Overall the beam setting is comparable between prediction and clinically employed beam setting.

Dosimetric Comparison:

Boxplots of dosimetric comparison is shown in Figure 2. Overall distribution is comparable between two groups with no statistical significance observed.

Case Study:

Figure 3 shows one example case outlined in the red box in Figure 1. EG-Plan showed somewhat different beam pattern from clinically employed beam setting. EG-Plan adopts more anteriorly oriented beam bouquet than more equal-spaced beam setting used by the clinical plan. EG-Plan showed improved liver V20Gy from clinical plan (48.1% vs 51.5%). This case indicates that he evidence based model is capable of understanding the reasoning of selecting and arranging beam setting.

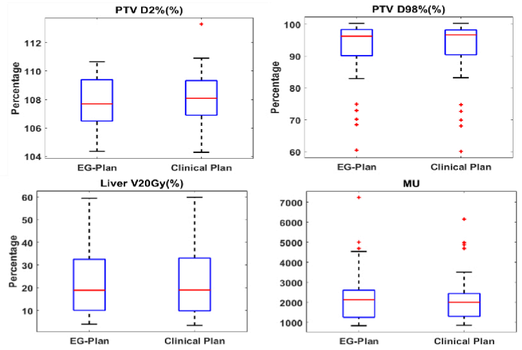

Figure 2 Boxplot of PTV D2%, D98%, liver V20Gy and total MU between EG-Plan (left) and clinical plan (right).

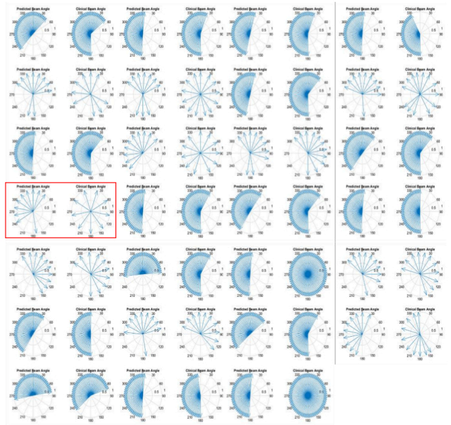

Figure 1 Beam Setting for all 27 cases. Left figure is evidence based prediction beam setting while right figure is clinically employed beam setting. IMRT beams are plotted as isolated arrows while VMAT is plotted per 5 degree control points. Red box denotes the case analyzed in case study.

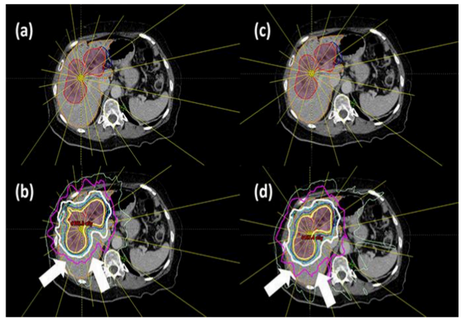

Figure 3 An example case comparing (a) EG-plan beam and (c) clinical plan beam. Corresponding dose distribution is shown in (b) for EG-Plan and (d) clinical plan. White arrow points to improved 20Gy isodose line in the EG-Plan.

CONCLUSIONS

The evidence driven beam setting model yielded similar plan quality as hand-crafted clinical plan. It is capable of capturing human's reasoning in beam selection decision making. This model could facilitate decision making for beam angle selection choices while eliminating lengthy trial-and-error process of adjusting beam setting during liver SBRT treatment planning.

ACKNOWLEDGEMENTS

This study is partially supported by NIH R01CA201212 research grant and Varian master research grant

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