Improving the efficiency of prostate inverse planning with Ideal Planning Assistant

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Introduction:

Prostate cancer is the third most common form of cancer worldwide (7.1% of new cases for all sites) and is the second most frequent cause of cancer related death among men, behind lung cancer. (1) Due to this high incidence rate, radiotherapy clinics will likely treat a large number prostate cancer patients. Therefore, improvements to the planning process for these treatments will greatly increase clinical efficiency. When treating prostate cancer, it is important to ensure that dose to the surrounding tissue and organs-at-risk (OARs) be minimized where possible, while still maintaining planning target volume (PTV) coverage. This can be challenging due to the close proximity of OARs, like the bladder and rectum. IMRT and its faster, continuous form volumetric modulated arc therapy (VMAT) demonstrate a considerable advantage in treatment due to their improved dose distribution and OAR sparing when compared to three-dimensional conformal radiotherapy. (2) Inverse planning with IMRT allows planners to select volumes and give them dose goals for the treatment planning system to meet by automatically altering how it plans to deliver the dose. This gives the planner a large degree of control over the plan, however it comes with the drawback of increased planning time, which can be made even longer based on the experience of the planner and their knowledge of realistic dose distribution goals. Developing a means to ensure IMRT prostate treatments achieve uniform dose distribution to the target, limited normal tissue dosage, and short planning times is key to improving planning efficiency and consistency.

Ideal Planning Assistant (IPA), a program developed in house at the Mays Cancer Center at the University of Texas Health in San Antonio, was created to streamline the treatment planning process and produce plans that exceed clinical acceptability in a shorter period of time, by providing the planner with tools to use while inverse planning. IPA utilizes the Ray Tracing algorithm to quickly model the dose distribution within the patient and creates dose clouds and a dose volume histogram (DVH) to reflect treatment of the target to an assumed, uniform prescribed dose. Further adjustments can be made by lowering the modification level on the structures window for each OAR which tells the program to lower the dose to the OAR and move it elsewhere, while maintaining the "uniform" coverage of the PTV. Depending on how much focus the physician intends to give to each OAR, they can indicate a level-of-sparing for the OARs and the program will determine how the dose can be distributed to achieve it. Once the physician has finished creating this theoretical plan, it is exported to the treatment planning system as structures that indicate discrete dose levels to model the actual dose around. A final DVH is also produced to be used during inverse planning. (Figure 1) With these tools at their disposal, the planner should be able to drive the plan to mirror the theoretical plan, or at least be close to it, within a shorter window of time. **The goal of this study is to evaluate IPA for its effectiveness in decreasing necessary planning time and pushing plans to a superior quality.**

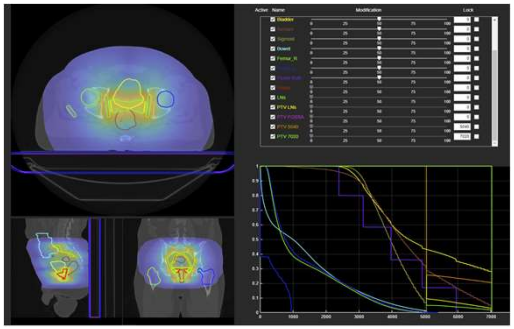

Figure 1: IPA interface, including patient three-view dose model window (left), structure modification window (upper right), and ideal, theoretical DVH (lower right)

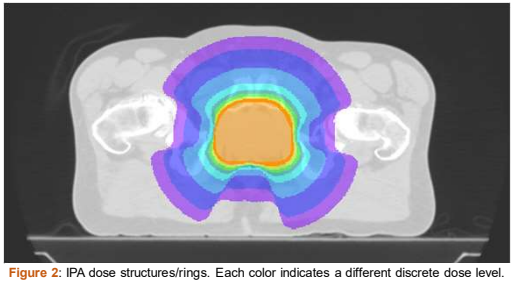

Figure 2: IPA dose structures/rings. Each color indicates a different discrete dose level.

Materials and Methods:

For this study a sample of ten previously treated, prostate cancer patients were selected and anonymized. First, each patient was planned normally with VMAT. Two 10MV, full rotation dynamic arcs in opposite directions were used, with the collimator angle setting left to the planner's preference. An hour and a half was given for planning time, with a goal of lowering the dose to all OARs while maintaining a PTV coverage of or close to V100% ≥ 95%. The OARs evaluated consisted of the femoral heads, bladder, rectum, penile bulb, and sigmoid and bowel where applicable. Once the allotted time was reached, the plan was normalized to achieve the desired coverage. Rather than having specific goals for OARs, the planner simply tried to bring doses to the OARs as-low-as-reasonably-achievable (ALARA).

Next the patients were re-planned but with the assistance of IPA, while limiting the number of optimizations to however many the normal plans were able to reach within the hour and a half. For five patients, the plans were created using the dose structures, or rings, imported from IPA. (Figure 2) Each ring was designated a specific discrete dose level which the treatment planning system attempted to replicate through inverse planning. The remaining five plans were made utilizing the theoretical DVH as a basis by placing max DVH goals for each structure on the optimizer along where IPA predicted it could be. Planning order for all ten plans followed a similar structure: get uniform coverage of PTV, implement IPA tools to lower dosage to OARs, and reduce hot/cold spots within the PTV that arose from sparing. These plans were similarly normalized to achieve the desired target coverage.

The plans created with IPA were then compared to the normal plan, as well as the historical plans used to treat before, based on the following: the conformity index, the homogeneity index, and the mean dose to determine if IPA successfully improved treatment planning efficiency. Statistical significance between the plans was determined using a two-tailed T test.

$$\text{Conformity Index} = \frac{V_{95\%}}{Volume\ of\ PTV}$$

$$\text{Homogeneity Index} = \frac{D_{2\%} - D_{98\%}}{D_{50\%}}$$

Table 1
Homogeneity and conformity index for all 10 patients between the historical, normal, and IPA versions, with the averages

	Homogeneity Index			Conformity Index		
	Hist	Normal	IPA	Hist	Normal	IPA
1	0.0386	0.0406	0.0520	0.99986	0.99999	0.99999
2	0.0538	0.0602	0.0504	0.99936	0.99667	0.99843
3	0.0569	0.0428	0.0378	0.99679	0.99987	0.99994
4	0.0540	0.0699	0.0588	0.99957	0.99219	0.99812
5	0.4631	0.0477	0.0576	0.90601	0.99986	0.99902
6	0.1289	0.0196	0.0261	0.96891	0.99997	0.99997
7	0.0333	0.0704	0.0581	0.99779	0.99938	0.99922
8	0.0650	0.0348	0.0396	0.99947	0.99995	0.99963
9	0.0389	0.0253	0.0400	0.99997	0.99997	0.99997
10	0.0594	0.0359	0.0525	0.99139	0.99999	0.99994
Avg.	0.0992	0.0447	0.0473	0.98591	0.99878	0.99942

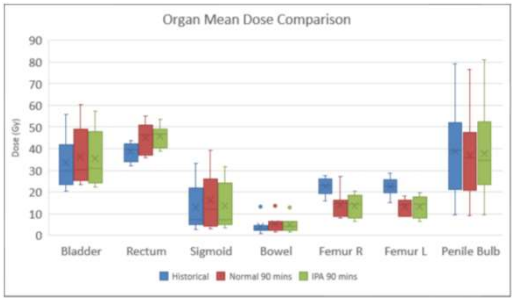

Figure 3: Dose comparison of each OAR for all three versions of the plan. "X" represents mean dose value and "---" represents median dose value

Table 2
Mean dose of each OAR averaged for all ten plans for each version. OARs listed in order of clinical importance

$$\text{Mean Dose} = \frac{\sum_{j=1}^{N} D_j}{N}$$

	Mean Dose (Gy)		
	Hist	Normal	IPA
Bladder	33.47	36.29	35.30
Rectum	38.77	44.74	45.77
Sigmoid	12.76	16.11	13.59
Bowel	4.35	5.41	5.02
Femur_R	22.62	14.18	13.64
Femur_L	22.57	13.25	13.39
Penile Bulb	38.98	37.18	37.81

Results:

For the homogeneity index and conformity index, the normal plans had the best homogeneity and the IPA plans had the best conformity. Both showed improvement over the historical plans. (Table 1) IPA assumes that the dose to the target is uniform throughout for its model, demonstrated by the vertical line in the IPA DVH. (Figure 1) While ideal, this is impossible realistically as there will always be falloff towards the edges of the target and heterogeneity in the patient density ensures hot and cold spots within the target. Making this assumption hinders IPA, as its dose ring structures and DVH create unrealistic expectations and end up driving up the dose in the PTV. Improved conformity in the IPA plans can potentially be attributed to the dose rings, aiding in shaping the dose to the target better than the simple expansion based rings used in normal planning. However, these differences may simply be due to small variations in plan quality as they are not statistically significant.

For the mean doses to the OARs, IPA showed a small improvement to the bladder, sigmoid, bowel, and right femur. On the other hand, the normal plans had slightly lower doses to the rectum, penile bulb, and left femur. These differences were not statistically relevant, but may be due to the IPA plan pushing for more sparing, in an effort to achieve a global minimum of plan quality. Due to the overlap between the PTV and the bladder and rectum, IPA would have underestimated the amount of sparing possible for these structures, since it maintains perfect coverage of the PTV in its calculation. This would potentially account for the increase in mean rectal dose.

Greater changes are seen between the current plans and the historical plans, where the historical plans had statistically significant sparing to the rectum and bowel but increased doses to the femoral heads. This is likely due to the past physician specifying an order of importance to the previous planner, in regards to OARs. The rectum is seen as the crucial OAR for sparing during prostate radiotherapy due to the bleeding, pain, and incontinence that can follow from rectal toxicity. (3) Hip toxicity can also present severe pain and lead to hip replacement, but these complications are unusual and more often caused by age or degenerative joint disease rather than radiotherapy. (4) Due to this, physicians will justify allowing more dose to the femoral heads, if it means increased sparing to the rectum. This is demonstrated by the increased mean dose to the femoral heads and subsequent decrease in dose to the rectum seen in the historical plans. This presents an issue in comparing old and new plans, since the plans made in this study simply sought to achieve ALARA for all OARs. If this study is conducted again, it would be beneficial to decrease the rectum further than the femoral heads in the modification window of IPA, so more effort is placed to the lower the rectal dose and better reflect clinical practice.

Conclusion:

With the addition of IPA as a planning tool, little improvement is seen between the normal and IPA plans, and any improvements shown are not statistically relevant. A larger sample size may be beneficial in demonstrating IPA's value as a planning tool. Furthermore, the study could be refined to better reflect clinical practices in sparing importance, with the bladder and rectum being higher than the femoral heads. IPA does however show usefulness in pre-planning, being able to give an estimation of what is the best possible plan that can be achieved and if considerations need to be made if it shows that planning constraints are not realistic.

References:

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