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Personalized Planning with Pinnacle Auto-Planning and PlanIQ™ Feasibility

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Introduction

Pinnacle Auto-Planning is a software application that simplifies the planning process through the use of protocol templates and automatic optimization tuning methods. One of the advantages of Auto-Planning is that it automates the actions taken by an experienced planner to create an optimal IMRT or VMAT plan. These actions include, but are not limited to, creating optimization structures and managing structure overlaps, as well as controlling dose in hot and cold spots.[1] Auto-Planning has been shown to improve efficiency of optimization and tends to improve quality of plans compared to manual optimization.[2,3,4]

PlanIQ Feasibility (Sun Nuclear Corp, Melbourne, FL) is a tool that allows a priori estimation of the best possible sparing of organs at risk in high-energy photon planning. Feasibility predicts doses to OARs through a model which benchmarks 3D dose clouds built outside targets thanks to series of energy-specific dose spread calculations reflecting observed properties of radiation distribution in media.[5] Feasibility allows personalization of OAR planning goals based on patient geometry.

In this paper, we illustrate the typical workflow for using Feasibility integrated with Pinnacle Auto-Planning.

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Methods

Personalized plan automation with PlanIQ and Auto-Planning

Auto-Planning runs through several separate optimizations without requiring user interaction to achieve the clinical goals set by the user as entry prescription. Because Auto-Planning automatically tunes optimization parameters to push OAR sparing while maintaining PTV coverage, users can get clinically acceptable plans generally by using generic protocol numbers as inputs to the optimization process by using generic protocol numbers as inputs to the optimization process. (Figure 1)

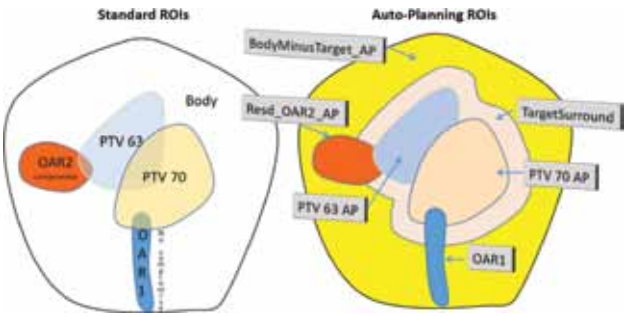

Figure 1

However, since the number of separate optimizations run by Auto-Planning software is finite, providing an improved seed value from which to start the optimization will improve the final optimization result. In addition, as recommended by APEx®[6] and ACR[7] accreditation standards, there is a desire to create personalized objectives based on patient actual anatomy.

There are several alternative options for personalization of planning goals, including Knowledge-Based solutions[8], Multicriteria Optimization[8] (MCO), and Overlap Histogram Analysis[9]. Of these options, the first two require a significant amount of user interaction, thus affecting consistency in plan quality, and the third is not yet commercially available. Since PlanIQ Feasibility is a model-based calculation[5], which provides a patient-specific estimation of the best-case scenario dose distribution informing the user of the achievability of treatment planning goals, the implementation is straightforward and requires little user intervention to utilize. Furthermore, PlanIQ provides tools for benchmarking results against a reference group.

Using PlanIQ to determine clinical goals for Auto-Planning

Auto-Planning OAR sparing goals are in the form of maximum dose, maximum mean dose, and maximum dose to a percentage of (Max DVH) the structure. The user has the ability to set priorities for each of these goals to “Low”, “Medium”, and “High”. Furthermore, the user can determine how overlaps between OARs and Targets are be handled through use of the “Compromise” selection (Figure 1). When “Compromise” is selected, shared voxels between targets and OARs are considered part of the target volume. Conversely, when “Compromise” is not selected, shared voxels between the targets and OARs are considered part of the OAR (Figure 2). For this reason, it is suggested that the planner generally select “Compromise” for goals on parallel OARs, such as the parotids, kidneys, etc., and not select “Compromise” for serial structures, such as the Spinal Cord and brainstem. This combination of goals and compromise settings can be set as a protocol in Auto-Planning, also referred to as a “Treatment Technique”. (Figure 2)

Figure 2

Planners can set the goals for Auto-Planning using information from the Feasibility DVH (FDVH) in PlanIQ (Figure 3).

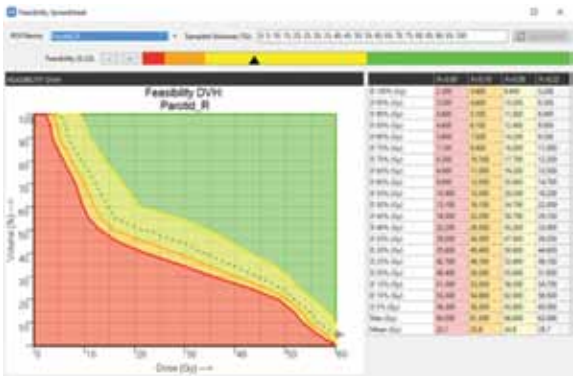

Figure 3

Running PlanIQ Feasibility on a given patient's CT image and unique geometric relationship between the target volume and OAR creates a Feasibility DVH (FDVH). The FDVH for a given OAR is divided into three main regions. The green region is deemed dosimetrically easy to achieve, yellow is more challenging, orange is difficult, and the red region indicates an area where the DVH cannot be achieved without sacrificing PTV coverage. The dotted line illustrates the actual predicted DVH for the selected organ. That predicted DVH can be modified by using the slider bar indicated by the black triangle to assign a "Feasibility Value" between 0 (along the red line), 0.1 (orange line), 0.5 (yellow line) and 1 (green line) in Figure 3. In an ideal situation for Auto-Planning to improve quality, the majority of OARs should lie between the yellow and orange regions. The closer to the red region, the more the optimizer will be forcing the sparing.

Pinnacle planners send RT Structures, DICOM Images, and planning goals using the "Export to PlanIQ" button shown in the lower left corner in Figure 2. Once they are imported into PlanIQ, a feasibility analysis is run, and planning goals based on Feasibility within PlanIQ are set. Those goals are then imported into Auto-Planning using the "Import from PlanIQ" button in Figure 2 to complete the treatment technique and plan optimization.

Results

Ten, 3-arc VMAT head and neck cases were run through Auto-Planning, first by using OAR sparing inputs based on typical NRG protocol guidelines. These are designated as "3-arc" in Figure 4. The same cases were re-run, first by simply replacing the initial clinical goals with values from Feasibility in the lower portion of the yellow area ("Challenging") defined by the FDVH. For this test, the Feasibility value nominally assigned was 0.22 (represented by the dotted line in Figure 3). If however, the goal in the protocol was lower than this, the protocol goal was used. For example, in the case above where the FDVH predicted PAROTID_R sparing to be over 28.7Gy mean dose if the feasibility curve was in the yellow area, the value used for input to AP was instead changed to 26Gy, reflecting the protocol standard. Finally, for structures that were deemed unable to be spared based on feasibility, planning goals for these structures were removed. This is documented in Figure 4 as the "Feasible" plan.

Next, these same cases were run using the FDVH results to guide various clinical decisions. The first example of guided clinical decision-making using this information includes changing priority of planning objectives based on the FDVH. For example, if the FDVH predicts a possible maximum dose to the SPINALCORD of 25Gy, when the toxicity endpoint which is to be avoided is 45Gy, the priority of the planning goal was decreased to "Medium" because of the wide margin between the two values. Conversely, if the structure to be spared had a FDVH showing the best possible scenario sparing to be very close to the protocol limit, the priority was changed to "High", such as with the example PAROTID_R above.

A second example of using Feasibility to guide decision-making was adding DVH optimization objectives. As seen in the FDVH curve in Figure 3, it was observed that there was a curvature to the DVH for which optimization could be improved by adding a DVH objective point close to the inflection point of the curve to guide the optimizer to match the shape of the FDVH curve.

Plan Quality Metric Component	Objective(s)	3_arc	Feasible	% Change	Clinical Feasible	% Change
[PTV_6000] V[60.0Gy] (%)	> 95	95.79	95.86	0.07	95.52	0.14
[PTV_6000] V[55.8Gy] (%)	> 99	99.98	99.97	0.01	99.97	0.01
[PTV_6000] D[0.03cc] (Gy)	< 66	64.58	64.58	0.01	64.79	-0.16
[CTV_6000] V[60.0Gy] (%)	> 99	99.12	98.98	0.07	98.83	0.15
[PTV_5400] V[54.0Gy] (%)	> 95	98.16	97.75	0.21	97.49	0.34
[PTV_5400] V[50.2Gy] (%)	> 99	99.99	99.99	0.00	99.97	0.01
[CTV_5400] V[54.0Gy] (%)	> 99	99.63	99.81	-0.08	99.62	0.01
[PTV_4800] V[48.0Gy] (%)	> 95	98.84	98.39	0.23	97.95	0.45
[PTV_4800] V[44.0Gy] (%)	> 99	100.00	99.99	0.00	99.97	0.01
[CTV_4800] V[48.0Gy] (%)	> 99	99.39	99.32	0.03	98.95	0.22
[SPINALCORD] D[0.03cc] (Gy)	< 48	32.20	23.55	15.51	26.51	9.69
[SPINALCORD_05] D[0.03cc] (Gy)	< 45	40.31	31.09	12.91	34.77	7.45
[BRAINSTEM_03] D[0.03cc] (Gy)	< 50	32.44	21.20	20.96	28.38	10.31
[PAROTID_L] Mean dose (Gy)	< 26	25.86	21.84	4.07	22.82	6.89
[PAROTID_R] Mean dose (Gy)	< 26	27.12	26.93	0.15	23.34	6.65
[SUBMANDIBULA_L] Mean dose (Gy)	< 39	49.66	49.22	0.44	49.42	0.24
[SUBMANDIBULA_R] Mean dose (Gy)	< 39	44.54	46.37	-2.02	42.86	1.92
[LARYNX] Mean dose (Gy)	< 35	32.15	28.49	6.02	24.63	13.23
[PHARYNX] Mean dose (Gy)	< 40	40.41	38.39	2.56	35.34	6.13
[ORALCAVITY] Mean dose (Gy)	< 32	30.11	27.47	4.58	23.26	12.83
[ESOPHAGUS_UP] Mean dose (Gy)	< 30	22.04	16.97	12.99	13.69	16.83
[MANDIBLE] D[0.03cc] (Gy)	< 63	61.26	60.79	0.41	61.34	-0.08

- 3 cases PAROTID_R not feasible to be spared
- 1 case PAROTID_L not feasible to be spared
- 7 case SUBMANDIBULA_L not feasible to be spared
- 5 case SUBMANDIBULA_R not feasible to be spared
- 1 case LARYNX not feasible to be spared

Figure 4

As seen in Figure 4, over the 10 cases sparing increased across nearly all structures when going from “3_arc” to Feasible, with the one exception of the SUBMANDIBULA_R gland. It is important to note, however, of the 10 cases, 5 of them had plan geometries for which sparing of the SUBMANDIBULA_R gland which was impossible, according to Feasibility, and therefore were removed from the optimization parameters in the “Feasible” plans.

When going from the “Feasible” plans to the “Clinically Feasible” plans, we can see that the dose to the SPINAL CORD, SPINALCORD_05, and BRAINSTEM_03 actually increased a little. The final dose, however, is well below the protocol objective of less than 45Gy. This is because, as described above, the priority on these structures between the “Feasible” plan and the “Clinical Feasible” plan changed from “High” to “Medium”. Furthermore, with the exception of the MANDIBLE, which was partially encompassed by the PTV60 in many cases and therefore was not able to be spared significantly and the SUBMANDIBULA_L gland, which was basically unchanged, all other structures showed improved sparing.

Discussion

In this study, a Feasibility value of 0.22 was assigned to all OARs, with exceptions to that logic noted above. This value was chosen for two reasons. The first is that Auto-Planning is designed to push sparing beyond the values set by the user, so a value was chosen that would provide AP a starting point for further optimization, yet not to that final value. It should be noted that a fair amount of modulation was allowed in this study, with three full arcs used in optimization, with each arc having a different collimator angle (Beam 1 = 15 degrees, Beam 2 = 345 degrees, Beam 3 = 90 degrees). Further testing has shown that if fewer arcs are used, allowing for less modulation, a more relaxed Feasibility number that outlines the outer edge of the yellow region and closer to the green region may be needed to prevent over-modulation and undesirable optimization effects such as loss of conformability. The second reason this Feasibility value was used was that it reduces the variability of the inputs for the purpose of improved quantification of the effects. The planner is encouraged to practice with different Feasibility values and possibly even varying the Feasibility value per structure based on the desired clinical sparing. Furthermore, the planner may choose to add more than one DVH hint point to guide the optimizer for better matching of the shape of the FDVH.

Feasibility analysis in this case was used to provide achievable planning goals during the planning process.

An additional application of Feasibility would be for physicians to use it as a pre-planning tool to provide treatment planners with achievable goals instead of relying on generic protocols. This is in line with ACR and APEx™ recommendations of the creation of a patient-specific planning intent.[6,7]

Conclusion

Auto-Planning optimization using clinical OAR sparing goals based on FDVH information provided by PlanIQ feasibility has been shown to improve sparing compared to using generic protocol values as inputs. PlanIQ Feasibility can also be used to improve clinical decision making by providing the planner with achievability of objectives prior to initiation of planning, allowing for inputs of patient-specific, personalized values based on patient geometry.

Auto-Planning combined with PlanIQ provide a powerful combination of functionalities to help achieve the highest quality, personalized treatment plans.

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