BRAINLAB

STEREOTACTIC RADIOSURGICAL OPTIMIZATION FOR CRANIAL INDICATIONS

White Paper

Although a number of optimization algorithms exist for volumetric modulated arc therapy (VMAT), such algorithms have typically been designed with conventional radiotherapy in mind. For stereotactic radiosurgery, many centers still prefer to use forward, conformal planning techniques to achieve the steep dose gradient demanded by tighter normal tissue constraints. Optimization in Elements Cranial SRS* provides a way of automatically creating SRS plans that meet such demands in an efficient and intuitive environment.

ALGORITHM DESCRIPTION: Trajectory Optimization

When manually optimizing the arc setup, e.g. in iPlan RT Dose, the best results are achieved by taking an indication-specific, default setup and then simultaneously optimizing the table and gantry angles. Trajectory optimization does the same but automatically. In order to minimize dose to organs at risk (OARs), the problem is approached by adjusting the table and gantry angles of the arcs with a cost function according to either OAR or clinic-related requirements:

- OAR-related
  - Minimize overlap in beams eye view (BEV) between PTV and OARs
  - Minimize radiological depth of PTV

- Clinic-related
  - Minimize deviation of table angles from the user-defined original setup
  - Minimize deviation of gantry angles from the user-defined original setup

The importance of each of these goals depends on the user. Goals can be set to a weight between 0 and 1. Here 0 corresponds to an ignored parameter, 0.5 is a medium weighting and 1 designates the highest importance. By adjusting all of the weights, any desired importance can be set to any of the goals.

If the optimal solution is not significantly better in terms of the goals than the original setup, the solution is discarded and the user-defined, original setup is restored.

CLINICAL EXAMPLE: Trajectory Optimization On and Off

In a practical sense, the trajectory optimization translates into an automated way of both shortening the arc length and adjusting the table angle (see Figure 1). The clinical benefit of such adjustments can be seen in Figure 2 comparing mean OAR doses with and without trajectory optimization.

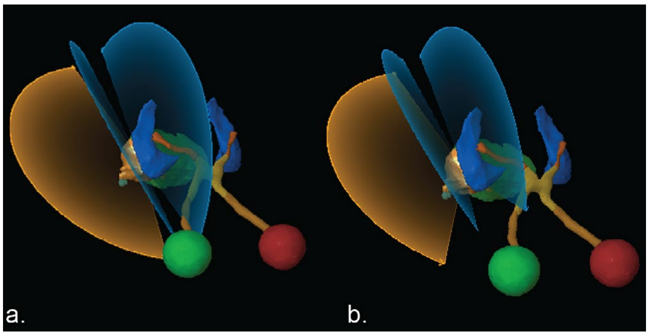

Figure 1a. Arcs before optimization and b. Following optimization for a right acoustic neuroma.

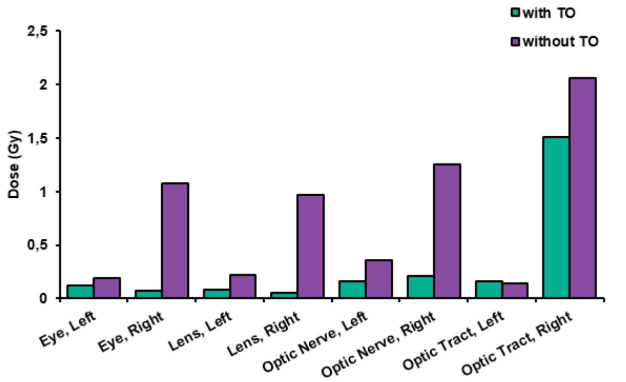

Figure 2. Corresponding case with mean doses to OARs reduced by optimizing the table angle and gantry rotation length.

In addition to arc trajectory optimization, a number of other algorithms directly relating to the dose objective function are implemented. Instead of numerically adjusting weighting and prioritization directly, these are controlled more intuitively through sliders. The following is a brief description of their functionality.

ALGORITHM DESCRIPTION: Normal Tissue Sparing

Generating a steep dose gradient with high conformity is essential to any SRS treatment plan. To achieve and control this, the importance of normal tissue surrounding the PTV can be controlled. This includes not only the OARs, but also extends into all other areas outside the PTV.

Internally, the optimization creates a "ring object" enveloping (but not including) the PTV. It has a thickness of 35 mm and is hidden from the user. The normal tissue slider has positions ranging from "low" to "high". At all selectable positions, the optimizer tries to reduce the dose to the normal tissue but the penalty on dose in normal tissue varies. The result is that higher normal tissue sparing produces better (i.e. lower) Conformity Index (Paddick CI) [1] and Gradient Index (GI) [2] values.

CLINICAL EXAMPLE: Opposing Extremes of the Normal Tissue Slider

By adjusting the weighting parameters of the ring object, the dose gradient and shape can be quickly adjusted to create various scenarios depending on clinical need. Figure 3 shows high normal tissue sparing in the top row and low normal tissue sparing in the bottom row. The dose gradient is primarily affected in the normal tissue region outside the organs at risk (shown in Figure 3 as outside the brainstem) because these are spared anyway.

*Work in progress

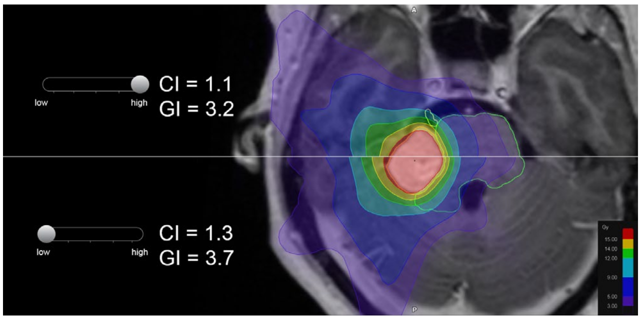

Figure 3. Normal tissue sparing with upper image showing setting at high resulting in improved Conformity Index and Gradient Index.

ALGORITHM DESCRIPTION: SRS Optimization

In certain cases, it is desirable to increase the monitor units to improve the treatment plan (e.g. OAR sparing). There is, however, an upper limit to the number of Monitor Units a single arc can deliver.

To account for this, the segments of an arc can be cloned if required (referred to here as 'portioning'). This allows a further increase in monitor units. The technical relevance of this portioning is that a solution can be found which other optimizers have discarded simply due to machine constraints. This is especially useful in SRS treatments since high doses are delivered in few fractions. Clinically, this benefits the user who does not need to worry about the number of arcs required for a certain fractionation scheme.

ALGORITHM DESCRIPTION: Modulation

Volumetric Modulated Arc Therapy (VMAT) [3] differs from Dynamic Conformal Arc Therapy (DCAT) through the extra component of dose modulation. In general, a highly modulated plan shows some or all of the following characteristics:

- Large number of monitor units
- Large amount of leaf movement between control points
- Irregularity of leaf shape within one segment (i.e. non-conformal)
- Complex fields

The optimizer tries to reduce the amount of modulation for each position of the modulation slider. The slider, however, sets the importance of modulation reduction. The range is from "low" to "high" shown in Figure 4. Although the position "low" will not produce a DCAT plan, it will, in addition to the behavior described above, deactivate the dose modulation between control points. In other words, it will disable changes in both dose rate and gantry speed between control points, as well as further penalize leaf motion. This produces plans that are similar to DCAT plans with manually adjusted leaf positions. A clinical consequence of this is potentially less demanding QA requirements for treatment plans produced at the "low" modulation setting.

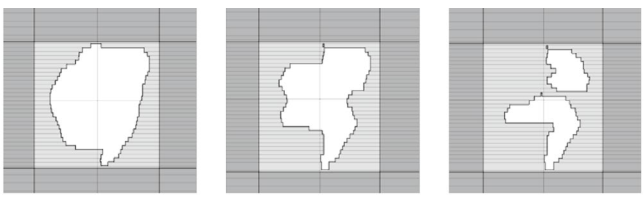

Figure 4. Positions low, middle and high of the modulation slider show varying degrees of modulation, evident from the complexity of the MLC segments.

ALGORITHM DESCRIPTION: Weighting

The trade-off between target coverage and OAR sparing varies from case to case. To help users efficiently determine the optimal balance in PTV-OAR trade-off, the following goals are taken into consideration through slider positioning:

- PTV weighting
  - Higher target coverage
  - Higher target homogeneity
  - Improved fulfilment of upper dose constraint
- OAR weighting
  - Improved fulfilment of OAR constraints
  - Improved normal tissue sparing

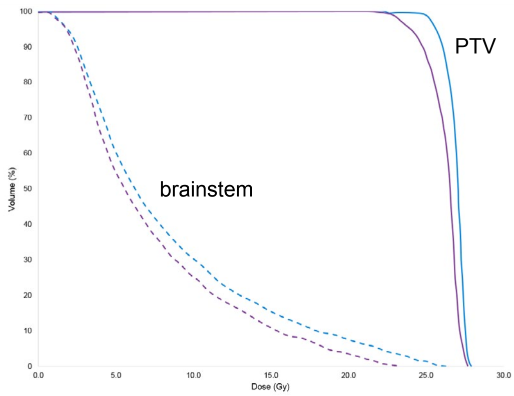

Figure 5. PTV weighting shown in blue and OAR weighting shown in purple.

CLINICAL EXAMPLE: Opposing Extremes of the Weighting Slider

The aforementioned parameters are taken into consideration when moving the position of the weighting slider to PTV weighted or OAR weighted. Consider the examples shown in Figure 5 for the two extreme positions of the weighting slider (PTV and OAR). By using automatic treatment planning algorithms, it is possible to generate multiple plans in minutes and quickly examine the trade-offs of multiple scenarios.

CONCLUSION

Elements Cranial SRS provides a means of automatically creating deliverable SRS plans in a consistent manner. By providing an intuitive interface to the optimization algorithm, SRS need not be a time-consuming task reserved primarily for planners with decades of experience. Elements Cranial SRS is a single solution allowing treatments ranging from the classical, penumbra-focused plan through to complex targets.

REFERENCES

[1] I. Paddick, "A simple scoring ratio to index the conformity of radiosurgical treatment plans," Journal of Neurosurgery, vol. 93, no. supplement 3, pp. 219–222, Dec. 2000.

[2] I. Paddick and B. Lippitz, "A simple dose gradient measurement tool to complement the conformity index," Special Supplements, vol. 105, no. 7, pp. 194–201, 2006.

[3] K. Otto, "Volumetric modulated arc therapy: IMRT in a single gantry arc," Medical Physics, vol. 35, no. 1, p. 310, 2008.

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