REPORTS OF PRACTICAL ONCOLOGY AND RADIOTHERAPY 21 (2016) 571–578

Available online at www.sciencedirect.com

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journal homepage: http://www.elsevier.com/locate/rpor

Original research article

An empirical method for automatic determination of maximum number of segments in DMPO-based IMRT for Head and Neck cases

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ARTICLE INFO

Article history:
Received 11 February 2016
Received in revised form
15 May 2016
Accepted 8 September 2016

Keywords:
IMRT
Number of segments
Aperture-based IMRT
DMPO
Anatomy-guided segments

ABSTRACT

Aim: An empirical scheme called "anatomy-guided segment counting (AGSC)" is proposed for automatic selection of maximum number of segments (NOS) for direct machine parameter optimization (DMPO).

Background: Direct machine parameter optimization (DMPO) requires the user to define the maximum number of segments (NOS) in order to proceed with an optimization process. Till date there is no established approach to arrive at an optimal and case-specific maximum NOS in DMPO, and this step is largely left to the planner's experience.

Materials and methods: The AGSC scheme basically uses the Beam's-eye views (BEVs) and other planning parameters to decide on appropriate number of segments for the beam. The proposed algorithm was tested in eight H&N cases. We used Auto Plan feature available in Pinnacle3 (version 9.10.0) for driving the DMPO optimization.

Results: There is about 13% reduction in the composite objective value in AGSC plans as compared to the plans employing 6 NOS per beam and 10% increase in the composite objective value in AGSC plans as compared to the plans employing 8 NOS per beam. On the delivery efficiency front, there is about 10% increase in NOS in AGSC plans as compared to the plans employing 6 NOS per beam specification. Similarly, there is about 19% reduction in NOS in AGSC plans as compared to the plans employing 8 NOS per beam specification.

Conclusion: The study demonstrates that the AGSC method allows specifying appropriate number of segments into the DMPO module accounting for the complexity of a given case.

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http://dx.doi.org/10.1016/j.rpor.2016.09.004

1. Background

In inverse planning for IMRT, conversion of the fluence profiles into deliverable segments is an important step. The conversion is performed by a variety of algorithms, out of which aperture based optimization methods[1–3] have become important and wide spread in clinical use. The advantage of aperture-based method is that the delivery constraints are directly incorporated in the inverse problem, which leads to the production of good quality plans with good deliverability. Direct machine parameter optimization (DMPO) is a commercial implementation of aperture-based optimization available in Pinnacle3 treatment planning system (TPS). With DMPO, MLC settings are produced directly within the optimization process. Therefore, there is no need for conversion, filtering or other kinds of post-processing, and there is no plan quality degradation.[4] A detailed description of the DMPO algorithm has been discussed elsewhere.[4,5] In general, DMPO results in considerably lesser number of segments and MUs as compared to the conventional two-step IMRT process, without any compromise in the plan quality.[6–8]

DMPO requires the user to define the maximum number of segments (NOS) in order to proceed with the optimization process. If the maximum NOS defined by the user is too small, it can affect the plan optimality[8,9]; conversely, if the maximum NOS is too large, it can directly impact the treatment efficiency. Many investigators have studied the impact of maximum NOS specification in DMPO plans and provided some recommendations.[8–13] But till date, there is no established approach to arrive at an optimal and case-specific maximum NOS in DMPO, and this step is largely left to the planner's experience. Also in many instances, a suitable maximum NOS is found by a trial-and-error method, which is time consuming. Since DMPO optimizer invariably returns a plan with NOS close to the maximum number specified, specifying a number close to the optimal value is important in obtaining a good plan.

2. Aim

In this work, a novel and empirical scheme for automatic and case-specific selection of maximum NOS in DMPO-based IMRT is proposed. The scheme basically uses the segmented anatomic projections (SAPs) of the Planning Target Volume (PTV) and organs-at-risk (OARs) in the Beam's-eye-view (BEV) to determine the maximum NOS for each beam. Hence, the scheme can be regarded as "anatomy-guided segment counting (AGSC)" algorithm, the patent application of which can be found here.[14]

3. Materials and methods

3.1. *Brief description of the algorithm*

1. First, the AGSC algorithm takes as input the SAPs in the BEV to determine the areas of organs-at-risk (OAR) overlap with the composite target volume (i.e. the geometric sum of all PTVs).

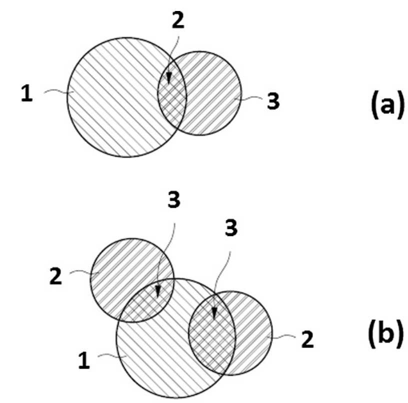

Fig. 1 – An illustration of different arrangement classes based on the segmented anatomic projections (SAPs) of the PTV and OAR and their overlaps in the Beam's-eye-view (BEV). (a) The arrangement of SAP 1 of PTV and SAP 3 of an OAR, which comprise a single overlapping region 2 (first arrangement class). (b) A further arrangement of SAP 1 of PTV and of SAP 2 of two OARs (second arrangement class).

Table 1 – A look-up table for the number of Boolean combinations (number of segments) for possible PTV-OAR overlaps based on arrangement class.

Number of OAR overlaps	Maximum NOS per beam		
	First arrangement class	Second arrangement class (before Boolean reduction)	Second arrangement class (after Boolean reduction)
0	1	Nil	Nil
1	3	Nil	Nil
2	Nil	6	3–6
3	Nil	9	6–8
4	Nil	12	8–11

2. Then, the number of regions overlapping with the composite target is counted and a combinatorial combination of these regions is derived from a set of Boolean combinations applicable to the segmented structures (Fig. 1 and Table 1).
3. The combination of sub-regions computed above along with other processes, such as segment pruning using minimum segment size (MSS) and Boolean reduction (BR) are used to arrive at the maximum NOS per beam.
4. The maximum NOS per beam obtained above is summed over all beams and the resulting total maximum NOS (per plan) is fed into the DMPO algorithm as a delivery constraint.
5. The DMPO algorithm uses AGSC-predicted maximum NOS and produces the optimal fluence along with deliverable segments.

3.2. *Detailed description*

3.2.1. *Boolean combinations*

The number of segments determination in the AGSC method is adapted to determine a number of regions of overlap between