Efficient SIB-IMRT planning of head & neck patients with Pinnacle$^3$-DMPO

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In the Netherlands, about 2,300 people per year are diagnosed with a malignant tumor in the head and neck region. About 450 of them are referred to the Radboud University Nijmegen Medical Centre. Most of them undergo radiotherapy, either as a sole treatment, or in combination with surgery or chemotherapy. As part of the tailored radiation therapy most patients will be treated with Intensity Modulated Radiotherapy (IMRT).

IMRT treatment planning of Head and Neck (H&N) patients can be a complex and time-consuming task due to concave, irregular target volumes which are close to or even overlap with critical structures such as the parotid glands.

The radiation oncologist defines the clinical aims, e.g. the prescribed dose to the target volume(s) and the maximum dose to the critical structures. In the IMRT treatment planning process, these clinical aims are specified mathematically in the form of objective functions.

During treatment planning several decisions have to be made: e.g. how many beams should be employed, under which angle should they enter the patient and what type of objectives functions have to be used to find a good balance between tumor coverage and sparing of critical structures. However, in a clinical environment where it is essential for the patient to start treatment shortly after diagnosis, it is important that the planning procedure is straightforward and time-efficient. The goal is therefore to find a standard set of initial conditions for the optimization process, i.e. number of beams and gantry angles, IMRT parameters (such as the number of segments), and planning objectives with which a satisfactory clinical plan can be achieved for most of the patients.

In our institute a planning study was performed for patients suffering from oropharyngeal cancer, using the Pinnacle$^3$ treatment planning system (Philips Medical Systems, Best, the Netherlands). The results are reported below.

**IMRT**

In external beam radiotherapy the tumor is irradiated with shaped beams of ionizing radiation (X-rays or electrons) that are generated by a linear accelerator. The individual shaping of the beams to match the 3D shape of the tumor has become known as 3D Conformal Radiation Therapy (3D-CRT). Although it is called conformal radiotherapy, it does not have the ability to conform the isodose distribution well to concave shaped target volumes.

In Intensity Modulated Radiotherapy (IMRT) a more conformal dose distribution can be achieved, to include concave targets, by introducing an additional degree of freedom: the beam intensity across each of the radiation beams. Figure 1 is a schematic representation of the beam intensity profile for one of these beams.

IMRT (which is basically an advanced form of 3D-CRT) stepped into the limelight of radiation oncology more than a decade ago, and since then it has become a “hot topic” among medical physicists and radiation oncologists. Following technical developments by manufacturers of treatment delivery systems and treatment planning systems, the technique has been implemented in many centers around the world, where it is used to treat a variety of cancers such as H&N, brain and prostate cancer. The aim of
IMRT is to conform the radiation more tightly to the tumor than would be possible with 3D-CRT, so that the total dose to the tumor can be increased while at the same time the dose to the neighboring tissues is minimized.

The intensity-modulated beams can be delivered by means of a Multi Leaf Collimator (MLC), which is also used in conventional radiotherapy. The MLC allows the beam to be shaped in a fast and controllable way. It consists of tungsten leaves that can be moved independently of each other to achieve the desired aperture shape. In our clinic, IMRT beams are created by delivering several fields (or segments) with different shapes from the same beam direction (see Figure 2).

A mathematical optimization process - so-called inverse planning - is used to determine the shape and intensity of these MLC radiation apertures. An “optimal” intensity distribution, i.e. one that meets the objectives as closely as possible, is found by dividing the beam into very small beams (“beamlets”) and by varying the intensity of each individual beamlet. However, the “optimal” intensity distribution then has to be transformed into a deliverable series of MLC segments. This process is called leaf-sequencing or segmentation.

Until recently, the treatment planning process comprised several steps for the treatment planner. First an ideal fluence (intensity) map had to be created and the corresponding treatment plan reviewed. If the treatment plan was clinically acceptable, the segmentation process was started. This conversion usually led to a deterioration of the quality of the treatment plan, so that it had to be carefully reviewed once more. Finally, to improve the quality of the treatment plan, a segment weight optimization procedure had to be started, in which the weights of the segments were further optimized.

Inverse planning with DMPO
With the introduction of the DMPO (Direct Machine Parameter Optimization) algorithm [1], IMRT planning with Pinnacle® has become less time-intensive [2] and more straightforward. The treatment planner can start the whole optimization simply with “a touch on a button”: the conversion of the ideal fluence map into segments takes place during the optimization process.

The treatment planner has to decide beforehand after how many iterations the ideal fluence map is to be converted. After the conversion, DMPO continues to optimize the weight and the aperture form of the individual segments by moving the leaf positions (the number of segments stays the same). Now only the final, clinically deliverable treatment plan needs to be reviewed and evaluated.

Pinnacle® also adds the possibility of creating command files (known as “scripts”) with which the beam set-up, additional contours and a set of objectives are set up automatically. This speeds up the planning process.

H&N IMRT in Nijmegen
In the Radboud University Nijmegen Medical Centre, patients with advanced oropharyngeal tumors are treated with a Simultaneous Integrated Boost (SIB) technique [3]. 50.3 Gy is given to the elective volume and 68 Gy to the boost target volume in 34 treatment sessions (fractions) over 5.5 weeks, delivering one fraction per day during the first 4 weeks and twice daily during the last 1.5 weeks (according to an accelerated scheme).

The IMRT treatment (“step-and shoot”) is applied using Elekta SLi-Precise machines (Elekta, desktop v. 5) with the Oncentra -Visir Record & Verify Software (Nucletron, v. 2.1).

Step by step to the “class solution”
To keep the planning procedure time-efficient and straightforward, a standard set of beams and objectives has to be found.

The number of beams
In an earlier planning study (before working with DMPO), 5-, 7-, and 9-beam set-ups were compared. The 7-beam set-up was found to be a good compromise between plan quality and treatment time on the linear accelerator.
Now seven uniformly spaced coplanar beams are routinely used.

The number of segments
The allowed maximum number of segments was varied (40, 60, 80, 100) to find a good compromise between quality and feasibility. More than 60 segments did not lead to significant improvements in the treatment plans [4], but would result in a longer time for the patient on the treatment couch. Currently a maximum number of 60 segments is employed.

Before starting the optimization process, due consideration has to be given to the use of additional contours which help to sculpt the dose distribution and subsequently simplify the planning process.

Additional contours – Organ At Risk (OAR)
Figure 4a shows a transverse slice with the clinical Regions of Interest (ROI). Next to it, Figure 4b shows the same slice with additional contours added to guide the optimization process. Any overlapping ROI’s are separated to avoid conflicting objectives. For example, the Planning Target Volume (PTV) is subtracted from the parotid gland and the resulting “parotid gland minus PTV” ROI (Figure 4b) is designated as a separate objective. To achieve an additional sparing of the parotid gland further away from the PTV, a third contour for the parotid gland is created. This “extra parotid” contour is the same as “parotid gland minus PTV” but with an extra margin towards the PTV to allow for the application of a more strict objective.

Additional contours – Planning target volume
To further guide the optimization and conform the dose to the target volume, additional ROI’s – known as “guiding volumes” – are created. These may be adjusted after the first optimization run.

An inner ring is created for the elective volume (red) as well as the boost target volume (blue) (Figure 4b). These inner rings receive a minimum dose objective to prevent an underdosage at the periphery of the PTV. An outer ring (light blue) is also created for the boost target volume in order to avoid a spreading of high dose into the elective target volume.

The elective volume is split into a cranial and a caudal part (Figure 5) to help keep the dose in the caudal part between 95% and 107% of the prescribed dose, as required by the ICRU.

Objectives
Different sets of objective functions for target volumes and critical structures were tested, including dose, dose-volume (DV) and Equivalent Uniform Dose (EUD) based objectives [5]. For example, a minimum (or maximum) dose objective tries to keep the dose in the tumor (critical structure) above (or below) a specified value.

The set of objectives below resulted in clinically acceptable treatment plans for all 25 patients.

Figure 3. The 7-beam set-up offers a good compromise between plan quality and treatment time.

Figure 4. Transverse slice showing Regions of Interest (ROI).

Figure 4a. Transverse slice showing the elective volume (outlined in red), the boost volume (outlined in blue) and the parotid glands (outlined in green).

Figure 4b. Transverse slice showing additional contours in colorwash: “parotid gland minus PTV” (green), inner ring elective volume (red), inner ring (blue) and outer ring (light blue), boost volume and “guiding volumes” (yellow).
studied and it is now used for all our clinical patients. The exact dose levels and weights still require some fine-tuning during the planning process and are therefore not shown.

Of course, this set of objectives is not the only one to produce satisfactory treatment plans. Others may produce similar results as well. However, it is a set that works well in our clinic with the given combination of planning system, treatment technique, treatment equipment, delineation and evaluation.

Table 1. Set of objectives currently used for oropharynx patients.

<table>
<thead>
<tr>
<th>ROI Objective</th>
<th>ROI</th>
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<tbody>
<tr>
<td>PTV&lt;</td>
<td>Max dose</td>
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<tr>
<td>PTV&lt;</td>
<td>Min dose</td>
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<tr>
<td>PTV&lt;</td>
<td>Uniform dose</td>
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<tr>
<td>PTV ring inside</td>
<td>Min dose</td>
</tr>
<tr>
<td>PTV ring outside</td>
<td>Max dose</td>
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<tr>
<td>PTV cran</td>
<td>Max DVH</td>
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<tr>
<td>PTV cran</td>
<td>Min dose</td>
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<tr>
<td>PTV cran</td>
<td>Uniform dose</td>
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<td>PTV caud</td>
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<td>PTV caud</td>
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<tr>
<td>PTV caud</td>
<td>Uniform dose</td>
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<tr>
<td>PTV ring inside</td>
<td>Min dose</td>
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<tr>
<td>Larynx - PTV</td>
<td>Max EUD</td>
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<tr>
<td>Parotid gland- PTV</td>
<td>Max EUD</td>
</tr>
<tr>
<td>Brain stem</td>
<td>Max EUD</td>
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<tr>
<td>Spinal cord</td>
<td>Max EUD</td>
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<tr>
<td>Guiding volumes</td>
<td>Max dose</td>
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<tr>
<td>Ex -ROI</td>
<td>Max DVH</td>
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Results
For 25 consecutively treated clinical patients this set of objectives has turned out to be adequate to obtain a satisfactory plan. Due to the standardized set of beams, objectives, IMRT parameters and additional ROI's, the whole planning process can be done in one day, and hence does not require more planning time than a conventional plan. With the additional use of scripts the planning time can even be shortened.

Conclusions
With the DMPO module in the Philips Pinnacle³ treatment planning system, inverse planning for IMRT has become more straightforward and less time intensive. After initially investing time in finding a good set of objectives, oropharynx treatment planning with DMPO can be done in the same time period as conventional planning. This allows the clinical introduction of IMRT for all oropharynx patients and raises the standard of care for the patients.

References


