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*Oesophagus IMRT*

# Automated selection of beam orientations and segmented intensity-modulated radiotherapy (IMRT) for treatment of oesophagus tumors

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## Abstract

***Background and purpose*: For some treatment sites, there is evidence in the literature that five to nine equiangular input beam directions are enough for generating IMRT plans. For oesophagus cancer, there is a report showing that going from four to nine beams may even result in lower quality plans. In this paper, our previously published algorithm for automated beam angle selection (Cycle) has been extended to include segmented IMRT. For oesophagus cancer patients, we have investigated whether automated orientation selection from a large number of equiangular input beam directions (up to thirty-six) for IMRT optimisation can result in improved lung sparing.**

***Materials and methods*: CT-data from five oesophagus patients treated recently in our institute were used for this study. For a prescribed mean PTV dose of 55 Gy, Cycle was used in an iterative procedure to minimise the mean lung dose under the following hard constraints: standard deviation for PTV dose inhomogeneity 2% (1,1 Gy), maximum spinal cord dose 45 Gy. Conformal radiotherapy (CFRT) and IMRT plans for a standard four field oesophagus beam configuration were compared with IMRT plans generated by automated selection from nine or thirty-six equiangular input beam orientations. Comparisons were also made with dose distributions generated with our commercial treatment planning system (TPS), and with observations in the literature.**

***Results*: Using Cycle, automated orientation selection from nine or thirty-six input beam directions resulted in improved lung sparing compared to the four field set-ups. Compared to selection from nine input orientations, selection from thirty-six directions did always result in lower mean lung doses, sometimes with even fewer non-zero weight beams. On average only seven beams with a non-zero weight were enough for obtaining the lowest mean lung dose, yielding clinically feasible plans even in case of thirty-six input directions for the optimisation process.**

**With our commercial TPS we observed the same contra-intuitive, unfavourable results as reported in the literature; nine field equiangular IMRT plans had substantially higher mean lung doses than plans for the conventional four field set-ups. For all cases, the Cycle plans generated from nine equiangular input directions were superior compared to similar plans generated with our commercial TPS.**

***Conclusions*: For the studied oesophagus cancer patients the best plans for IMRT were obtained with Cycle, using automated beam orientation selection from thirty-six input beam directions. The lowest mean lung doses could be obtained with, on average, a selection of only seven beams with non-zero weight.**
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Investigations regarding the selection of beam orientations in combination with IMRT have started long ago. Theoretical considerations were given by Bortfeld and Schlegel [1]. Exhaustive search experiments have been carried out by Soderstrom and Brahme[14,15].

Based on case studies it was concluded that with IMRT adequate results would be obtained with five to nine equiangular beams directions; adding more beams would not significantly increase the quality of the plan [15,16]. Only for smaller numbers of beams, optimisation of the beam directions would result in improved plans

Webb[17] and Mageras and Mohan [3] have described an approach to the problem of orientation selection that allows a large number of input orientations and they solve the problem using the beam weight space instead of using the phase space. Simulated annealing was used to find a solution and the results contained many beam orientations with a non-zero weight. Extrapolation of this method to IMRT may

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result in a search space that is too large to derive a solution within a reasonable time frame.

Beam orientation selection was also the subject of many more recent papers [2,4–13]. Practical methods for orientation selection and IMRT were proposed by Rowbottom et al. [13] and later by Pugachev et al. [6–9]: after the selection of the number of beams, a result may be obtained in a two-step process using e.g. fast simulated annealing for orientation sampling and fluence optimisation using a gradient technique.

Experiences with current IMRT-algorithms and pre-selected beam orientations have pointed at some unexpected problem for tumour sites, like head-and-neck and the thorax region. Compared to IMRT plans with 9 equi-angular beam arrangements, selection of fewer beams with properly chosen orientations, positively affected the dose distribution [4,5]. A possible explanation for this phenomenon has been given by Rowbottom et al. [13], who mentioned that some IMRT algorithms have difficulty to reduce the dose in OAR's in low dose regions.

Using the CT-data sets of five previously treated oesophagus cancer patients, and the CORVUS(v3.0), an inverse TPS, Nutting et al. [5] investigated the use of IMRT for the conventional four field set-up (anterior, posterior, and two posterior oblique beams), and for a nine field equiangular configuration. For the conventional beam set-up, IMRT plans had lower mean lung doses than the corresponding conformal plans. However, compared to the IMRT plans for the four field configuration, the nine field IMRT plans did unexpectedly result in higher mean lung doses.

In this paper we have extended our previously published algorithm for automated beam angle selection, designated Cycle, [18,19] to include segmented IMRT. Both for Cycle and for our commercial TPS (Cadplan/Helios), we have investigated, for oesophagus cancer patients, whether orientation selection from a large number of equiangular input beam directions for IMRT optimisation, can result in decreased mean lung doses, compared to the standard four field set-up. Comparisons were made with the study mentioned above by Nutting et al. [5]. As our commercial TPS did not allow the use of a mean organ dose as a treatment objective, like in [5], minimisation of the lung volume receiving a dose higher than 18 Gy ($V_{18}$) was applied as an indirect means to reduce the mean lung dose. In Cycle, both minimisation of the mean lung dose as well as minimisation of $V_{18}$, are possible. Using Cycle, we compared these two optimisation schemes to investigate whether the rather poor results of our commercial TPS could be attributed to the use of this indirect lung dose minimisation ($V_{18}$).

## Methods and materials

In this study, treatment plans were designed for oesophagus cancer patients. The general objectives and constraints were similar to those in the study by Nutting et al. [5]. The main objective was a minimum mean lung dose, while delivering the prescribed mean PTV dose without violation of the imposed hard constraints on the dose homogeneity in the PTV and the maximum dose in the myelum. The most important question to be addressed was whether IMRT optimisation with a large number of input beam directions (up to thirty-six) can be used to improve on the mean lung dose obtained for the conventional beam set-up, with an anterior beam, a posterior beam, and a left and a right posterior oblique beam. Plans were generated with our commercial TPS and with Cycle, an in-house developed package for automated beam angle selection [18,19].

### Oesophagus patients

CT data sets were used of five patients with a tumour in the thoracic oesophagus, that were treated previously in our clinic. For each patient, twenty-five CT-slices (1 cm slice distance) were used. To provide for a set-up margin, the inner outline of the vertebrae, designated spinal cord in this paper, was delineated instead of the myelum.

Treatment plans were generated with objectives and constraints similar to [5]. The main objective was to generate plans with a minimum mean lung dose. The prescribed mean PTV dose was 55 Gy. Regarding PTV dose homogeneity a maximum standard deviation of 1.1 Gy, (2% of mean PTV dose), was tolerated. The maximum acceptable spinal cord dose was 45 Gy. Both lungs were considered as one organ. Only the lung volume outside the PTV was considered for optimisation. In agreement with Nutting et al. [5] no constraints were used for the mediastinum and the heart.

### Dose calculation engine for Cycle and segmented IMRT

Automatic beam angle selection with Cycle is based on pre-calculated, three-dimensional single beam input dose distributions. Any number of input directions $\theta$ can be used. In this study the maximum was thirty-six with 10° intervals. The input dose distributions were calculated with a dedicated dose calculation engine coupled to Cycle. This algorithm is based on 3D ray-tracing, and uses an effective path length method for correction of tissue heterogeneities. The CT-data of the patient is used as input. Unit beam weight has been defined to be 1 Gy at $d_{max}$ at the source-to-axis distance. In a previous study [19] it was established that the resulting dose distributions agree well with the results obtained with our commercial TPS. The latter observation was confirmed in the study described in this paper. Instead of the dedicated dose calculation engine, input from any TPS may be used.

For each $\theta$, the uniform field distribution $U_{\theta,u}(x, y, z)$ and four 60°-wedge distributions $U_{\theta,60,\phi}(x, y, z)$, for collimator angles $\phi$ of 0°, 90°, 180°, and 270° are involved. For the investigations described in this paper, the shapes of the fields were defined using the beam's-eye-view (BEV) projections of the PTV plus a 0.5 cm margin. To include segmented IMRT, Cycle has been extended for the use of beam segments that do not fully encompass the PTV. In this study, two segments were used to obtain improved sparing of the spinal cord:

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