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VMAT and IMRT in cervical cancer

# Comparison of VMAT and IMRT strategies for cervical cancer patients using automated planning

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ABSTRACT

*Background and purpose:* In a published study on cervical cancer, 5-beam IMRT was inferior to single arc VMAT. Here we compare 9, 12, and 20 beam IMRT with single and dual arc VMAT.
*Material and methods:* For each of 10 patients, automated plan generation with the in-house Erasmus-iCycle optimizer was used to assist an expert planner in generating the five plans with the clinical TPS.
*Results:* For each patient, all plans were clinically acceptable with a high and similar PTV coverage. OAR sparing increased when going from 9 to 12 to 20 IMRT beams, and from single to dual arc VMAT. For all patients, 12 and 20 beam IMRT were superior to single and dual arc VMAT, with substantial variations in gain among the study patients. As expected, delivery of VMAT plans was significantly faster than delivery of IMRT plans.
*Conclusions:* Often reported increased plan quality for VMAT compared to IMRT has not been observed for cervical cancer. Twenty and 12 beam IMRT plans had a higher quality than single and dual arc VMAT. For individual patients, the optimal delivery technique depends on a complex trade-off between plan quality and treatment time that may change with introduction of faster delivery systems.
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## Introduction

Volumetric modulated arc therapy (VMAT) and intensity modulated radiotherapy with static gantry angles (IMRT) have been compared for various tumour sites, both regarding plan quality and treatment time [1]. In most studies, VMAT was a new technology and plans were compared to previously delivered clinical IMRT plans. Systematic comparisons with variations in the number of IMRT beams and VMAT arcs are scarce [2–4]. Several studies on advanced cervical cancer have demonstrated reduced OAR doses with IMRT compared to 3D conformal radiotherapy [5–9]. To the best of our knowledge, only Cozzi et al. [10] have compared VMAT and IMRT for cervical cancer patients.

Recently, we have developed Erasmus-iCycle, an optimizer for automated, multi-criterial beam profile optimization and beam angle selection for coplanar and non-coplanar IMRT [11–17]. In Erasmus-iCycle, the common manual, trial-and-error tweaking of plan parameters by dosimetrists is replaced by a fully automated procedure, based on lexicographic optimization. The automation allows objective comparison of treatment strategies, e.g. with variable numbers of IMRT beams, or considering non-coplanar vs. coplanar IMRT [14–16]. Currently, Erasmus-iCycle optimizes beam fluences. For generation of clinical plans, Erasmus-iCycle plans are reconstructed and segmented in the clinical treatment planning system (TPS). In a recent prospective study, we have demonstrated superior plan quality of Erasmus-iCycle plans that were 'manually' reconstructed in the clinical TPS (semi-automatic plan generation), compared to the clinical routine of trial-and-error treatment planning. In 97% of cases, the treating physician selected the semi-automatically generated plan for treatment, rather than the IMRT plan generated manually by a dosimetrist without prior knowledge of the Erasmus-iCycle result [17]. Apart from the improved plan quality, the semi-automated procedure also reduced the planning hands-on time by 50% compared to manual planning.

Cozzi et al. [10] have retrospectively compared single arc VMAT plans with previously delivered 5-field equi-angular IMRT plans for treatment of cervical cancer patients. In this study, we have systematically compared single and dual arc VMAT plans with IMRT plans with 9, 12 and 20 beams. All these plans were generated semi-automatically (above). Apart from the mutual comparisons, the semi-automatic plans were also compared to clinically delivered 9-beam IMRT plans.

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## Materials and methods

### *Patients and clinical treatment plans*

Planning CT-scans of 10 randomly selected, previously treated cervical cancer patients were included in this study. All scans had delineated small bowel (SB), rectum, bladder, and a planning target volume (PTV). To establish the PTV, an internal target volume (ITV) was first constructed using a pretreatment established motion model from a full and an empty bladder CT-scan, which was then uniformly expanded by a 1 cm margin [18]. Patients were treated in prone position lying on a small bowel displacement system (belly board), and using step-and-shoot 9 field IMRT with 10-MV photons at a Synergy linear accelerator (Elekta AB, Sweden). The linacs were equipped with the MLCi2 multi-leaf collimator (MLC) and the dose rate was 600 MU/min. The prescription dose was 46 Gy delivered in 23 fractions. As defined by the clinical protocol, all plans were created to deliver $\geqslant$95% of the prescribed dose to a minimum of 99.5% of the PTV, and no more than 0.2% of the PTV should receive $\geqslant$110%. Cervical cancer target volumes are generally large. For this reason we did not use commonly applied $D_{98\%}$ and $D_{2\%}$ parameters for these patients to evaluate low and high PTV doses, respectively. The main planning goal was to create highly conformal plans providing the best sparing of the delineated OARs with a higher concern for the SB which has the most severe complications [19]. All plans were generated with our clinical TPS (Monaco version 3.3, Elekta AB, Sweden).

### *Systematic comparisons of planning strategies*

For each patient, 5 plans were semi-automatically generated in a two-step process. In the first step, Erasmus-iCycle ([13], and below) was used for fully automatic generation of a high quality 20-beam equi-angular IMRT plan. Using the Erasmus-iCycle results for guidance, an expert planner (Abdul Wahab M. Sharfo) then manually designed 5 plans with the clinical TPS; single arc VMAT (VMAT), dual arc VMAT (2VMAT), and IMRT plans with 9 (9DMLC), 12 (12DMLC) and 20 (20DMLC) equi-angular beams, delivered with dynamic MLC. To this purpose, the Erasmus-iCycle output was used to generate a patient specific plan prescription for Monaco [20]. For all plans, the goal was to maximally approach (or supersede) the corresponding Erasmus-iCycle plan results, considering the established hard constraints and priorities for the various objectives (details below). In order to avoid bias in planning results, plan generations for individual patients were spread out in time. Moreover, for each patient, the five plans were generated in an arbitrary order, and consecutive generation of plans for a single patient was avoided. The expert stopped working on the plans if plan quality levelled off and no significant further improvement was expected; there was no time limit. As in clinical practice, semi-automatic plans were generated for 10-MV beams, the MLCi2 multi-leaf collimator, and a maximum dose rate of 600 MU/min.

Generated plans were visually inspected by the clinician participating in this study (Jan Willem M. Mens) to assess acceptability for clinical use. For small bowel, the volumes receiving >15 Gy and >45 Gy, $V_{15Gy}$ and $V_{45Gy}$ [21], and the mean dose, $D_{mean}$, were used for quantitative plan comparisons. For rectum and bladder, $D_{mean}$ was used. Paired two-sided Wilcoxon signed-rank tests were performed to compare the different planning strategies. Differences were considered statistically significant for $p < 0.05$.

For a subset of 5 patients, all 5 semi-automatically generated plans were actually delivered at one of our treatment units in the absence of the patient to record treatment delivery times.

### *Automatic plan generation with Erasmus-iCycle*

Erasmus-iCycle has been described in detail in [13]. In this study, the optimizer was used for fluence profile optimization, using a fixed, equi-angular 20-beam setup (above). Plan optimization with Erasmus-iCycle is based on an *a priori* defined 'wish-list' with hard constraints, and prioritized objectives with goal values [11,12]. Each treatment site has a fixed wish-list. In several studies, we have observed superior plan quality with this approach compared to 'manual' trial-and-error tweaking of TPS parameters by dosimetrists in a clinical setting [14,16].

The cervical cancer wish-list as used in this study is presented in Table 1. The constraints for shells around the PTV at 1.5, 2.5 and 4 cm were defined to ensure a steep dose fall-off outside the PTV, as well as a conformal dose distribution. Among the objectives, PTV coverage had the highest priority. To achieve adequate coverage, the Logarithmic Tumour Control Probability (LTCP) was used as objective function [22]. A skin ring of 2 cm wide, extending from the body contour towards the PTV, was defined to control the entrance dose (priority 2). In line with current clinical practice, sparing of SB had a higher priority than reducing delivered dose to the rectum and bladder. Reduction of the mean SB, rectum and bladder doses was performed using a multi-level approach [13], i.e., by repeated use of the objective functions with decreasing priorities and goal values (Table 1).

## Results

### *Semi-automatic plan generation*

All generated plans were clinically acceptable. Based on achieved plan parameters of an Erasmus-iCycle 20-beam IMRT plan, the planner succeeded in all cases to generate a clinically deliverable 20DMLC Monaco plan with highly similar plan quality. As in the clinical plans, in all semi-automatically generated plans, at least 99.5% of the PTV received 95% or more of the prescribed dose, while the volume receiving >110% was below 0.2%. For the whole population and all plans, the minimum dose in the PTV-1 cc was 92.2% ± 1.1% of the prescribed dose. For each patient, differences in PTV coverage and PTV mean and minimum doses

**Table 1**
Applied wish-list for all study patients.

| Constraints | | | | | |
|---|---|---|---|---|---|
| | | Volume | Type | Limit | |
| | | PTV | Max | 105% of $D^p$ | |
| | | PTV shell 1.5 cm | Max | 75% of $D^p$ | |
| | | PTV shell 2.5 cm | Max | 65% of $D^p$ | |
| | | PTV shell 4 cm | Max | 50% of $D^p$ | |
| | | Unspecified Tissues | Max | 105% of $D^p$ | |
| **Objectives** | | | | | |
| **Level** | **Priority** | **Volume** | **Type** | **Goal** | **Parameters** |
| | 1 | PTV | ↓ LTCP | 1 | $D^p$ = 46 Gy, $\alpha$ = 0.75 |
| | 2 | Skin ring 2 cm | ↓ Max | 23 Gy | |
| | 3 | Small bowel | ↓ Mean | 40 Gy | |
| 1 | 4 | Rectum | ↓ Mean | 40 Gy | |
| | 5 | Bladder | ↓ Mean | 40 Gy | |
| | 6 | Small bowel | ↓ Mean | 20 Gy | |
| 2 | 7 | Rectum | ↓ Mean | 20 Gy | |
| | 8 | Bladder | ↓ Mean | 20 Gy | |
| | 9 | Small bowel | ↓ Mean | 10 Gy | |
| 3 | 10 | Rectum | ↓ Mean | 10 Gy | |
| | 11 | Bladder | ↓ Mean | 10 Gy | |
| | 12 | Unspecified tissues | ↓ Mean | – | |