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Head and neck IMRT

Volumetric modulated arc radiotherapy for carcinomas of the oro-pharynx, hypo-pharynx and larynx: A treatment planning comparison with fixed field IMRT

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ABSTRACT

Purpose: A planning study was performed to evaluate the performance of volumetric modulated arc radiotherapy on head and neck cancer patients. Conventional fixed field IMRT was used as a benchmark.
Methods and materials: CT datasets of 29 patients with squamous cell carcinoma of the oro-pharynx, hypo-pharynx and larynx were included. Plans for fixed beam IMRT, single (RA1) and double (RA2) modulated arcs with the RapidArc technique were optimised. Dose prescription was set to 66 Gy to the primary tumour (at 2.2 Gy/fraction), 60 Gy to intermediate-risk nodes and 54 Gy to low-risk nodal levels. The planning objectives for PTV were minimum dose >95%, and maximum dose <107%. Maximum dose to spinal cord was limited to 46 Gy, maximum to brain stem to 50 Gy. For parotids, mean dose <26 Gy (or median <30 Gy) was assumed as the objective. The MU and delivery time were scored to measure expected treatment efficiency.
Results: Target coverage and homogeneity results improved with RA2 plans compared to both RA1 and IMRT. All the techniques fulfilled the objectives on maximum dose, while small deviations were observed on minimum dose for PTV. The conformity index ($CI_{95\%}$) was 1.7 ± 0.2 for all the three techniques. RA2 allowed a reduction of $D_{2\%}$ to spinal cord of ~3 Gy compared to IMRT (RA1 $D_{2\%}$ increased it of ~1 Gy). On brain stem, $D_{2\%}$ was reduced from 12 Gy (RA1 vs. IMRT) to 13.5 Gy (RA2 vs. IMRT). The mean dose to ipsi-lateral parotids was reduced from 40 Gy (IMRT) to 36.2 Gy (RA1) and 34.4 Gy (RA2). The mean dose to the contra-lateral gland ranged from 32.6 Gy (IMRT) to 30.9 Gy (RA1) and 28.2 Gy (RA2).
Conclusion: RapidArc was investigated for head and neck cancer. RA1 and RA2 showed some improvements in organs at risk and healthy tissue sparing, while only RA2 offered improved target coverage with respect to conventional IMRT.
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The aim of the present study was to investigate the potential clinical role for head and neck cancer patients of RapidArc, the novel radiation treatment technique (Varian Medical Systems), which is based on volumetric intensity-modulated arc delivery, as opposed to intensity modulation which uses fixed gantry beams.

RapidArc falls into the category of intensity modulation therapy with arcs (IMAT) [1–4]. The Yu's group established the benefit of using multiple modulated arcs for complex cases [5,6]. The Ghent group applied IMAT techniques with multiple non-coplanar beams to pelvic treatments [7,8] proving equivalent or superior target coverage and improved sparing of OARs compared to conventional conformal treatments.

RapidArc is a technique based on an investigation from K. Otto [9] and it aims to (i) improve OARs and healthy tissue sparing compared to other solutions; (ii) maintain or improve the same degree of target coverage; and (iii) reduce beam-on time per fraction.

Faster treatments could have a clinical impact on patients in terms of comfort on couch, immobility and minimisation of internal organ displacement. It could also allow more time for imaging procedures allowing, in perspective, routine application of adaptive treatment strategies when changes are observed due to response to radiation as in patients with head and neck cancer.

IMRT in head and neck cancer patients has been largely investigated at both planning and clinical levels. Excellent reviews for treatment outcome and major toxicity patterns can be found in Gregoire et al. [10], Lee et al. [11] and Popovtzer et al. [12]. On the toxicity side, besides the major attention given to spinal cord and brain stem (with toxicity thresholds set in the proximity of 45–50 Gy for the first and at 50 Gy for the second), it is generally

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known that, for parotids, mean doses inferior to 25–30 Gy correlate well with substantial recovery of function within two years [13] (higher thresholds were observed for sub-mandibular glands in the range of 39 Gy [14]). To reduce dysphagia [15], sparing of constrictors (with mean dose below 60 Gy) highly correlated with improved swallowing, laryngeal elevation and epiglottic inversion. To manage ototoxicity [16], the mean dose to cochlea proved to be a highly significant factor with some threshold effect in the order of 60 Gy between high and low risks of auditory defects.

Volumetric IMAT has already been investigated for prostate, small brain tumours and cervix uteri cancer [17–19], i.e. on relatively simple clinical cases; head and neck is an ideal advanced benchmark for assessment of its conformal avoidance capabilities since the anatomical features of this location require highly sophisticated techniques to ensure adequate treatments.

The present study was initiated as a side investigation in the framework of a larger Phase II trial activated at Tata Memorial Centre (TMC) in Mumbai to investigate the role of IMRT vs 3D conformal radiotherapy in squamous cell carcinoma (SCC) patients at AJCC stages T1-3, N0-2b, and M0.

Material and methods

Patient selection and planning objectives

CT data (3 mm slice thickness) for a group of twenty-nine consecutively treated patients from the TMC protocol were selected for the purposes of planning. These patients had been randomized and treated on the IMRT arm of the protocol. The RapidArc planning was carried out on the same dataset at the Oncology Institute of Southern Switzerland.

Fourteen tumours were localised in the oro-pharynx district, eight in the hypo-pharynx and seven in the larynx. Fourteen patients presented T3 stage, twelve T2 stage and two T1 stage. Nodal involvement was mostly N0 (16), N1 (6) and N2 (7) stages; all patients presented no distant metastasis (M0). The main organs at risk (OAR) considered for all patients were ipsi- and contra-lateral parotids, spinal cord and brain stem. For some of the patients, additional organs were outlined by radiation oncologists depending on the indication including oral cavity, oesophageal constrictors, base of the tongue, cochlea, mandible, and vocal apparatus. These additional OARs were defined only for those patients where potential sparing was possible due to the target conformation. The healthy tissue was defined as the patient's volume covered by the CT scan minus the envelope of the various target volumes (PTV). Various PTVs were defined from the respective clinical target volumes (CTVs) adding 7 mm margins with 3D expansion. Dose prescription was set to 66 Gy at 2.2 Gy/fraction to the PTV including the primary tumour and the lymph-nodal metastases (PTV66 – high risk). Two additional elective PTVs were defined to be irradiated at 60 Gy (intermediate risk) and 54 Gy (low risk, sub-clinical disease) in the nodal regions (PTV60 and PTV54). All volumes were to be simultaneously treated according to the simultaneous integrated boost (SIB) approach. Due to target definition criteria, PTVs did not overlap and were not mutually included. All plans were normalised to the mean dose of PTV66. The mean volume of target volumes was PTV66: 342 ± 182 cm^3, PTV60: 107 ± 81 cm^3, and PTV54: 95 ± 54 cm^3 for the global group.

For all the PTVs, plans aimed to achieve minimum dose larger than 95% of the prescribed dose and a maximum lower than 107%. For the spinal cord, a maximum dose of 46 Gy was allowed. For the brain stem, the limit was set to 50 Gy. In the case of parotids, the planning objectives aimed to keep the mean dose below 26 Gy (or $D_{50\%} < 30$ Gy). For other organs at risk, the planning strategy was to minimise their involvement but no specific constraint was set.

Planning techniques

Three sets of plans were compared in this study, all designed on the Varian Eclipse treatment planning system (TPS) with 6 MV photon beams from a Varian Clinac equipped with a Millennium Multileaf Collimator (MLC) with 120 leaves (spatial resolution of 5 mm at isocentre for the central 20 cm and of 10 mm in the outer 2×10 cm, maximum leaf speed of 2.5 cm/s and leaf transmission of 1.8%). Plans for RapidArc were optimised selecting a maximum DR of 600 MU/min, and a fixed DR of 300 MU/min was selected for IMRT.

The Anisotropic Analytical Algorithm (AAA, version 8.6.02) photon dose calculation algorithm was used for all cases [20–23]. The dose calculation grid was set to 2.5 mm. RapidArc optimisation was performed with version 8.6.05.

Details for each planning method are as follows

IMRT

Reference plans were computed by selecting the 'conventional' intensity modulation approach as a benchmark, with fixed gantry and intensity-modulated beams delivering the dose by means of the sliding window approach [24–26]. Plans were individually optimised using seven or nine coplanar fields. The modulation fluences used in the present analysis are equivalent to the fluences approved for patient treatment, while final dose calculation was performed using the AAA, including heterogeneity management, instead of the Pencil Beam (used at TMC) for coherence with the RapidArc condition. MUs were kept fixed at the value from original calculation. It should be noted that in Eclipse, the optimisation process to generate the fluences and the final dose calculation are completely disentangled and therefore the determination of the optimal fluence is in no way influenced by the algorithm adopted afterwards.

RapidArc (RA)

To achieve the desired level of modulation required, the instantaneous dose rate (DR), MLC leaf positions and the gantry rotational speed were continuously varied by the RapidArc optimiser. To minimise the contribution of tongue and groove effect, the collimator rotation in RapidArc was kept fixed to a value different from zero. In the present study, the collimator was rotated to 40°. Details of the RapidArc process can be found in [9,15]. Two sets of plans were optimised and analysed. RA1 consisting of a single 360° rotation and RA2 consisting of two coplanar arcs of 360° were optimised simultaneously, to be delivered with opposite rotation (clock- and counter clock-wise). The application of two coplanar arcs aims to increase the modulation factor during optimisation. In fact, since each individual arc is limited to a sequence of 177 control points (i.e. ''elementary'' fields), the application of two independent arcs, simultaneously optimised, could allow the optimiser to achieve higher target homogeneity and lower OARs involvement at the same time, as seen in other IMAT applications [5–8]. In the previous investigations on RapidArc [17,18], the relative simplicity of cases did not require investigation of this feature of the optimiser.

Evaluation tools

Quantitative evaluation of plans was performed by means of standard Dose-Volume Histogram (DVH). For PTV, the values of $D_{98\%}$ and $D_{2\%}$ (dose received by the 98%, and 2% of the volume) were defined as metrics for minimum and maximum doses in association to $V_{95\%}$ $V_{107\%}$ (the volume receiving at least 95% or at most