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CLINICAL INVESTIGATION **Head and Neck**

RAPIDARC PLANNING AND DELIVERY IN PATIENTS WITH LOCALLY ADVANCED HEAD-AND-NECK CANCER UNDERGOING CHEMORADIOTHERAPY

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Purpose: Volumetric modulated arc therapy (RapidArc, Varian Medical Systems) permits the delivery of highly conformal dose distributions. We studied planning and delivery in patients who underwent RapidArc for locally advanced head-and-neck cancer (HNC).

Methods and Materials: A total of 35 consecutive patients who completed RapidArc with concurrent chemotherapy for Stages III-IV tumors of the oro- and hypopharynx/larynx in our center were identified. All underwent bilateral neck irradiation and 21 patients had at least N2 disease. A simultaneous integrated boost (SIB) delivered 70 Gy (in 2 Gy/fraction) to the planning target volume $(PTV)_{boost}$ and elective nodal regions (PTV_{elect}) received 57.75 Gy. A standard planning constraint set was used and constraints for parotid glands were individually adapted. Treatments were delivered using two arcs after all plans were verified in a solid water phantom using GafChromic External Beam Therapy films.

Results: RapidArc planning generally took 1.5–2 h, which was faster than with our previous seven-field intensity-modulated radiotherapy sliding window technique. Film dosimetry revealed that 0.6% of films exceeded a combination of dose differences ≥3% or distance to agreement ≥2 mm. More than 99% of both PTVs received ≥95% of the prescription dose. Average plan conformity index was 1.13 and mean dose to ipsilateral and contralateral parotid glands were 31.4 Gy and 26.1 Gy, respectively. The mean beam-on time was <3 min and mean number of monitor units was 426.

Conclusions: RapidArc achieved excellent target coverage and normal tissue sparing, with delivery completed in less than 3 min. RA is currently our standard intensity-modulated radiotherapy approach for advanced HNC.

Volumetric modulated arc therapy, RapidArc, Head-and-neck cancer, Locally advanced disease, Dose distribution.

INTRODUCTION

Head-and-neck cancer (HNC) accounts for 6% of all malignancies (1, 2), and almost half of all patients present with a locally advanced stage. Concomitant chemoradiotherapy has become the standard of care in such patients because it results in an absolute survival benefit of 6.5% at 5 years compared with radiotherapy only (3). However, acute and late treatment-related adverse effects are significant (4). Intensity-modulated radiotherapy (IMRT) enables the delivery of highly conformal dose distributions, and increases the therapeutic ratio as target volumes are often large and concave around nearby critical normal tissues. IMRT reduces complaints of dry mouth (5–9) and preliminary reports suggest that lowering the dose to pharyngeal constrictor muscles and larynx could lead to fewer difficulties with swallowing (10–12), all with comparable or superior locoregional control (13–16).

IMRT planning and quality assurance requirements are generally more complex and time-consuming than three-dimensional conformal treatment planning. A survey in the United States showed substantial variations between the prescribed and delivered IMRT doses (17), indicating the need for good quality assurance. Guidelines for proper commissioning of IMRT have now been published (18). Another feature of conventional IMRT plans is the requirement of more machine monitor units (MU) and multiple fixed-angle beams, which in turn leads to longer treatment times (19). RapidArc (Varian Medical Systems, Palo Alto, CA) is a novel radiation treatment technique that is based on volumetric modulated rotational delivery (20), as opposed to ''classic'' IMRT, which uses fixed gantry beams. By varying the speed of

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gantry rotation, multileaf collimator shape and continuously changing the fluence (dose rate), RapidArc delivers highly conformal IMRT plans in a short time (19, 21, 22). A recent planning study compared single and double RapidArc delivery with our standard seven-field sliding window IMRT in patients with locally advanced HNC (19). With similar target coverage, double arc plans had higher PTV homogeneity than single arc plans, and both RapidArc plans required less MU and shorter delivery times than conventional IMRT. Consequently, two arc delivery has replaced our all our conventional IMRT.

Some authors have cautioned that there may be tradeoffs between arc techniques which use short treatment times and the quality of dose conformality (23, 24). To confirm the findings of our recent planning study, we analyzed RapidArc planning and delivery parameters in a subgroup of HNC patients for whom IMRT plans were technically challenging.

METHODS AND MATERIALS

Patient selection

Between May 2008 and July 2009, 134 patients with HNC have been treated using RapidArc at our department. In order to evaluate a subset of treatment plans that required a high degree of dose modulation, we analyzed data from the first 35 patients with a primary Stage III-IV (American Joint Committee on Cancer, 6th edition) tumor without distant metastases, who also underwent concurrent chemoradiotherapy. Twenty-four patients had oropharynx cancer, 4 hypopharynx cancer, and 4 larynx cancer (Table 1). The majority (n = 27) received three cycles of concurrent single-agent cisplatinum 100 mg/m^2. Five patients received induction chemotherapy (taxotere-cisplatinum-5-FU) followed by weekly cisplatinum at 40 mg/m^2 during radiotherapy, 1 patient received weekly cisplatinum only, and 2 elderly patients received concurrent radiotherapy and cetuximab in a schedule described previously (25).

Patients were positioned in a five-point fixation mask (Posicast Thermoplastics, Civco Medical Solutions, Kalowa, IA). Gross tumor volume (GTV) was delineated on a contrast-enhanced planning computed tomography scan with 2.5-mm slice thickness. Target volumes were defined in most patients by coregistration of diagnostic MRI scans. Two patients had a planning positron emission tomography/computed tomography scan. The gross tumor volume was defined as the primary tumor and involved lymph nodes on both imaging modalities and examination under anesthesia. The ''boost'' clinical target volume (CTV_{boost}) comprised the gross tumor volume with a margin of 1 cm, and was corrected for anatomical boundaries. The ''elective'' CTV (CTV_{elect}) included the CTV_{boost} and bilateral elective lymph nodes: at least levels II-V, and level I-VI or retropharyngeal nodes when indicated and in accordance with published guidelines (26, 27). A margin of an additional 3 mm was taken to create planning target volumes (PTVs).

The organs at risk considered for all patients were ipsi- and contralateral parotids, the spinal canal and the brain stem, where appropriate.

Planning objectives and techniques

Dose prescription was set to 57.75 Gy at 1.65 Gy/fraction to the PTV_{elect} and 70.00 Gy at 2.00 Gy/fraction to the PTV_{boost} delivered as a simultaneous integrated boost. Patients were irradiated once per day, five times per week. Plans were generated by a team of dosimetrists experienced in RapidArc planning. A standard constraint set was used for RapidArc optimization, aiming to achieve at least 66.5 Gy (this is 95% of the boost dose) in 99% of the PTV_{boost} and 54.86 Gy (this is 95% of the elective dose) in 98% of the PTV_{elect}, while keeping the boost and elective volumes receiving 107% of their prescribed dose as small as possible, preferably <1% for the boost. The maximum doses specified for the spinal canal and the brain stem were 46 Gy and 54 Gy, respectively. Four dose objectives were set for parotid glands (PG) and adapted for each patient according to the position of the PG with regard to the PTVs. No specific constraints were used for the other healthy tissues, but a 1-cm thick ring was created around the PTVs and three constraints were used to enforce a steep dose falloff outside the target volumes (Table 2).

Optimization and dose calculation was performed using the Eclipse treatment planning system (version 8.2.23, Varian Medical Systems, Palo Alto, CA) with 6 MV photon beams from a Varian 2300 linac with the Millennium 120-mutileaf collimator. The Anisotropic Analytical Algorithm photon dose calculation algorithm was used with calculation grid was set to 2.5 mm. Details of the RapidArc delivery process were as described previously (19). In brief, two complementary coplanar arcs of 358° (one counterclockwise, one clockwise) were used. A sequential approach was used, in which the first arc plan was used as a base dose plan for the second arc plan, which compensated for possible under- or overdosage in the first arc plan, leading to a homogeneous dose in the PTV.

Quantitative evaluation of plans was performed by means of dose–volume histograms. To appreciate the target coverage in the areas where the PTV approaches the surface, a local virtual buildup of 6 mm (to overcome dose buildup under the skin) was used for optimization and quantification of the PTV coverage. After approval of the plan, the virtual buildup was removed and the dose distribution was recalculated for the actual treatment. A conformity index (CI), which is defined as the ratio between the patient volume receiving at least 95% of the prescribed boost dose and the volume of the PTV_{boost}, was calculated for all plans. In addition, the boost and elective volumes receiving at least 95% of the prescribed doses (V95), as well as the V107 were registered. The dose to 99% and 95% of the target volumes (D99 and D95, respectively) was also calculated.

Quality assurance

Quality assurance was performed as described previously (19). Briefly, dose distributions were analyzed using a 23-cm cube of polystyrene slabs. This phantom has multiple drawers for insertion of GafChromic External Beam Therapy films at different positions; therefore, dose verification can be done in multiple planes during a single treatment session. Dose verification of RapidArc plans was measured for the combination of the two arcs in at least three coronal planes throughout the phantom, and this was compared with the calculated dose of the same patient plan.

To ensure a correct patient setup, in 20 patients, two orthogonal on board kV images (OBI, Varian Medical Systems) were performed before each of the first three fractions, and the mean shift in three dimensions was calculated. From the fourth fraction onward, patient positioning was systematically done according to the calculated shifts. In 15 patients with PTVs close to critical structures (*e.g.*, the spinal cord or brainstem), daily online setup