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PHYSICS CONTRIBUTION

VOLUMETRIC INTENSITY-MODULATED ARC THERAPY VS. CONVENTIONAL IMRT IN HEAD-AND-NECK CANCER: A COMPARATIVE PLANNING AND DOSIMETRIC STUDY

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Purpose: Volumetric intensity-modulated arc therapy (RA) allows for rapid delivery of highly conformal dose distributions. In this study, planning and dosimetry of RA were compared with conventional intensity-modulated radiation therapy (IMRT) plans of head-and-neck cancer patients.

Materials and Methods: Computed tomography scans of 12 patients who had completed IMRT for advanced tumors of the naso-, oro- and hypopharynx were replanned using RA using either one or two arcs. Calculated doses to planning target volume (PTV) and organs at risk (OAR) were compared between IMRT and RA plans. Dose distributions for single arc (n = 8) and double arc (n = 4) plans were verified using film dosimetry in three to five coronal planes using a quality assurance phantom.

Results: RA plans allowed for a mean reduction in number of monitor units (MU) by nearly 60%, relative to seven field sliding window IMRT plans. RA plans achieved similar sparing of all OAR as IMRT. Double arc RA provided the best dose homogeneity to PTV with a lower standard deviation of PTV dose (1.4 Gy), vs. single arc plans (2.0 Gy) and IMRT (1.7 Gy). Film measurements showed good correspondence with calculated doses; the mean gamma value was 0.30 (double arc) and area of the film with a gamma exceeding 1 was 0.82%.

Conclusions: RA is a fast, safe, and accurate technique that uses lower MUs than conventional IMRT. Double arc plans provided at least similar sparing of OAR and better PTV dose homogeneity than single arc or IMRT.

Arc therapy, RapidArc, Film dosimetry, Planning study, Head-and-neck cancer.

INTRODUCTION

Radiotherapy for advanced head-and-neck carcinomas has shifted away from three-dimensional conformal radiotherapy (3D-CRT) to intensity-modulated radiotherapy (IMRT). The clinical benefits of sparing of the parotid glands have been demonstrated (1–4) with resulting reduction of xerostomia for patients treated with IMRT compared with CRT. The main drawbacks of IMRT are the more complex and time-consuming treatment planning process and the need for more extensive physics quality assurance. In addition, IMRT uses a larger number of static beams and monitor units (MUs) (5), which increases radiation delivery times up to 20 min and also patient exposure to low-dose irradiation.

In general, an increase in the number of IMRT beams increases the degrees of freedom (6), making intensity modulated arc therapy a logical next step in IMRT delivery. Several optimization methods for arc therapy based on direct aperture optimization have been described (7–9). A recently described novel approach for volumetric modulated arc therapy enables IMRT-like dose distributions to be delivered using a single rotation of the gantry (10). This concept has been clinically implemented in the Eclipse treatment planning software (Varian Medical Systems, Palo Alto, CA) under the name RapidArc (RA). In RA, the gantry speed and dose rate vary continuously during delivery. In addition, there is full leaf interdigitation, allowing multiple small islands of dose to be delivered to the planning target volume (PTV) at each gantry position. Clinical introduction of such new treatment techniques should be preceded by detailed validation of a range of plans (11, 12). Extensive studies on treatment planning or dosimetric validation and comparison of RA dose distribution with those obtained by existing IMRT techniques have not yet been reported. Because IMRT plans for head-and-neck cancer are demanding and

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Table 1. Patient characteristics

		UICC	V_{boost} (cm^3)	V_{total} (cm^3)
P1	Nasopharynx	III	375	615
P2	Nasopharynx	IIb	195	477
P3	Nasopharynx	III	221	837
P4	Nasopharynx	III	470	797
P5	Oropharynx	IVb	267	605
P6	Oropharynx + oral cavity	III	126	341
P7	Oropharynx	III	155	324
P8	Oropharynx	II	193	459
P9	Oropharynx	IVb	182	543
P10	Oropharynx	IVb	144	543
P11	Oropharynx	IVb	372	689
P12	Hypopharynx	IVa	160	447

Abbreviations: UICC = International Union Against Cancer; PTV = planning target volume.

All patients except for P7 had the bilateral lymph nodes included in the PTV.

require strong dose modulation, we selected these tumors for a comparative study of RapidArc plans with IMRT.

MATERIALS AND METHODS

Patient selection and contouring

Twelve patients with head-and-neck tumors were selected for the planning study (Table 1). These patients were randomly selected from the list of patients with head-and-neck cancer that have received IMRT treatment between 2007 and 2008 at our department. All cases were difficult to plan using conventional IMRT because of large, irregular tumor volumes. They were treated to two dose levels by means of a simultaneously integrated boost, delivering in 35 equal treatment fractions 70 Gy to the boost volume (PTVboost) and 57.7 Gy to the elective PTV (PTVelective). PTVboost consisted of the gross tumor volume and lymph nodes containing visible macroscopic tumor or biopsy-proven positive lymph nodes, to which a margin of 10 mm for CTV and 3 mm margin for PTV was added. PTVelective consisted of elective nodal regions (13,14) with a margin of 3 mm for setup errors. Segmented organs at risk (OAR) were the parotid glands, spinal canal, brainstem, oral cavity, and larynx region. The laryngeal region and oral cavity were arbitrarily delineated by a single clinician and they were restricted to a minimum distance of 5 mm from the PTV.

Conventional IMRT planning

The clinical (sliding window) IMRT plans were generated with seven coplanar equidistant fields of 6 MV. Optimizations and dose calculations were done with Helios/Eclipse versions 7.2.34 or 8.1.14 (Varian Medical Systems). For the optimization, the PTVs were reduced to 5 mm under the skin surface to prevent optimization problems in the build-up region. After optimization, the skin flash tool was used to extend the fluence of each field where necessary to cover the original PTV. PTVelective was reduced by a ring of 5 mm around PTVboost where a transient dose between 57.7 and 70 Gy was allowed. All IMRT optimizations were done by interactively adapting the objectives and their priorities. In the final plan, the objectives were to achieve PTV volumes receiving less than 95% of the prescribed dose ($V_{<95}$) smaller than 1% and $V_{>107}$ close to zero, although this was not followed strictly for PTVelective. For the OAR, the most important objective was to keep the maximum doses to the spinal cord and brainstem below 48 Gy and 55 Gy, respectively. The second main priority for OAR was to reduce the average dose to the parotid glands, where possible to below 26 Gy. Only after these objectives were met, reduction of the high-dose volume to the oral cavity and larynx region was attempted. To avoid hot spots of dose in the body of the patient, not delineated as one of the previously mentioned OAR, the rest of the body was subdivided in two to three extra OAR with objectives for the maximum dose. After optimization, the dose calculation was performed in Eclipse with the AAA algorithm (15,16) using a calculation grid of 2.5 mm. All the patients have been treated according to these IMRT plans using Varian Clinac 2300CD linear accelerators.

RA planning

RA is based on a stepwise optimization of leaf positions for a single arc, which is divided into 177 angles, named control points. Instead of trying to optimize all control points of the RA planning at once, which would be extremely time consuming, Otto showed that a progressively increase of control points can converge the optimization in a short time period to an optimal solution (10).

Table 2. Plan comparison between conventional IMRT and RapidArc (average of 12 patients)

	IMRT	Single Arc RA	Double Arc RA	Wilcoxon Matched-Pair Signed Rank Test (p)
V(boost)/cm^3	238 (126–470)			
V(elective)/cm^3	550 (324–837)			
MU	1108	439	459	0.000000
$V_{<95\%}$(boost)/%	1.2	1.6	0.6	0.097
$V_{>107\%}$(boost)/%	0.8	1.8	0.2	0.270
SD(boost)/Gy	1.7	2.0	1.4	0.014
$V_{<95\%}$(elective)/%	1.0	2.3	0.9	0.912
$V_{>107\%}$(elective)/%	6.8	13.7	3.0	0.043
SD(elective)/Gy	1.7	2.1	1.5	0.097
CI(boost)	1.14	1.21	1.24	0.014
CI(elective)	1.54	1.60	1.59	0.638
D_{mean}(left par)/Gy	35	37	34	0.347
D_{mean}(right par)/Gy	38	36	34	0.384
D_{mean}(larynx)/Gy	45	47	47	0.136
D_{mean}(oral cavity)/Gy	35	35	36	0.238

The Wilcoxon matched-pair signed rank test is listed for intensity-modulated radiation therapy (IMRT) vs. double arc RapidArc (RA).