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Dosimetric Comparison of Intensity-Modulated Radiotherapy versus 3D Conformal Radiotherapy in Patients with Head and Neck Cancer

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Abstract—

Purpose: To compare target dose distributions and dose to normal tissue using 3-dimensional conformal radiotherapy (3DCRT) versus intensity modulated radiation therapy (IMRT) in patients with nasopharyngeal carcinoma.

Methods: Sixteen patients with nasopharyngeal carcinoma. 3DCRT and IMRT plans were performed, the prescribed dose covering at least 95% of the clinical target volume (CTV), dose prescription for nasopharyngeal carcinoma was 70 Gy to the CTV70, 63 Gy to the CTV63 and 56 Gy to the CTV56, in 35 fractions, the dose constraints to organ at risks (OARs) as follows: maximum dose to (Brain stem, optic nerve and Optic chiasm) was 54GY, maximum dose spinal cord was 45GY and mean dose for parotid was 26GY

Results: IMRT has better coverage than 3DCRT; the doses to the spinal cord, brain stem and parotid gland from IMRT were lower than 3DCRT especially for parotid where the dose reduction was very significant.

Conclusions; Simultaneous integrated boost IMRT achieved comparable plans to 3D-CRT in complex nasopharyngeal carcinoma, IMRT results in improved dose distribution within CTV compared to 3DCRT. At the same time is also possible to reduce the dose to the organ at risk

Keywords—Nasopharyngeal carcinoma, 3DCRT, IMRT, Simultaneous integrated boost (SIB)

INTRODUCTION

Head and neck cancer arises from mucous lining of respiratory, digestive tracts, salivary glands, and lymph nodes. Head & neck cancer is histologically heterogeneous and organs at risk have less tolerance to radiation. Treatment planning for advanced head and neck cancer is a problem due to the complex shape of the target which commonly has an irregular concave shape volumes and the need to spare critical organs like the mandible, parotid glands, brainstem, spinal cord, and normal structures. These organs often lie very close to the target volumes critical structures, head and neck cancer presents a challenge for radiotherapy. Treatment with radiotherapy is curative for many patients with localized disease, but with current radiation techniques, dose is limited by both acute and late side effects and the anatomy of the head and neck region .The transition of radiotherapy for head and neck cancer from 3D conformal radiotherapy (3D-CRT) to intensity modulated radiation therapy (IMRT) made treatment of cancer easier and beneficial [1].

Nasopharyngeal carcinoma (NPC) is primarily treated with radiation therapy (RT). The basic principle of this treatment is to deliver a curative dose of RT to the tumor while minimizing dose to surrounding structures [2]. IMRT is a highly conformal treatment modality that is used when conventional methods of radiotherapy cannot deliver a tumor dose without exceeding critical structure tolerance [3–6].

IMRT is an optimal technical approach for treating head and neck cancer because of the anatomical complexity of the region with many critical and radiation-sensitive tissue structures in close proximity to the targeted cancer tissue [7, 8].there is evidence that IMRT correlates with decreased toxicity, without compromising local control (9) and particularly to concavely shape the contours of the target volume compared to conventional 3D conformal radiotherapy [10]

MATERIAL AND METHODS

Patients

Sixteen patients with advanced head and neck tumors nasopharynx were selected for the planning study. The patient’s group consisted of 4 female and 12 male patients, at diagnosis age ranging from 38 to 65 years. Plans were optimized with the aim to assess organs at risk and healthy tissue sparing while highly conformal target coverage. All patients underwent CT simulation in a supine position with the neck hyper extended using a head rest and custom plastic masks, to reduce the dose to the mandible and tongue. CT images were taken at 2mm slice thickness then transferred to focal system, PTV and OARs were delineated slice by slice and planning was done by means of a simultaneously integrated boost technique (SIB technique).

Clinical and Planning Target Volumes:

Clinical target volumes (CTVs) were generated as follows: (i) Nasopharyngeal carcinoma: CTV70 consisted of the GTV primary (GTV-P) GTV nodes (GTV-N) with a 10 mm margin for CTV (reduced to _1 mm where the volumes abutted critical structures, i.e. optic chiasm, brainstem); CTV63 included the entire nasopharynx and next echelon of nodes; CTV56 was the elective neck.

Dose Prescription

(i) Nasopharyngeal carcinoma: the dose prescription for nasopharyngeal carcinoma was 70 Gy to the CTV70, 63 Gy to the CTV63 and 56 Gy to the CTV56, in 35 fractions (as defined by RTOG 0522). Planning objectives were optimized to achieve the following parameters, For CTV, plans aimed to achieve the prescribed dose. Maximum dose to (Brain stem, optic nerve and Optic chiasm) was 54GY, the maximum dose spinal cord was 45GY and Mean dose for both left & right parotid was aimed to restrict below 26Gy.

Planning Techniques

3DCRT/IMRT

Two different treatment plans were generated for each patient: 1) 3DCRT planning and 2) IMRT, utilizing the same definition as 3DCRT planning, the conformal plan used the 3D information to design apertures and normalize the plan the planning goal was always adose homogeneity between –5% and +7%. Small hot spots up to +10% or less was accepted.

The 3D plans consisted of two opposite lateral fields, with anterior field configuration identical to the 2D plans, and the IMRT plans consisted of 7-9 fields equispace around the isocenter starting by posterior beam (gantry 180). All plans were generated with 6MV X-rays for Computerized Medical Systems (CMS) Inc.'s (St. Louis, MO). Optimization and calculations were done in the XIO planning system, XiO software release 4.64 superposition algorithms. The 3D plans were normalized such that the CTV D95 was equal to the prescribed dose. The IMRT plans were created for each CTV and also normalized such that the CTV D95 was equal to the prescribed dose. Treatments were delivered by a 6 MV linear accelerator of Siemens Oncor. The IMRT technique allows the treatment of various target volumes simultaneously with various doses per fraction and in turn allows escalation of the individual dose per fraction to the CTV I.

Treatment planning evaluation tools:

Dose volume histogram was used as a planning tool to estimate plans. The coverage on CTV was calculated as the ratio of target volume covered by 95% of isodose line divided by the volume of CTV. For CTV, D95% and D5% values were reported (dose received by 95% and 5% of the CTV volume) which represented the minimum and maximum doses.

The paired, two-tails Student's t-test was studied to evaluate the difference between the techniques.

RESULTS

Head and Neck (nasopharynx):

Acceptable plans were achieved for both IMRT and conformal plans, with CTV70 and CTV63but CTV56of conformal plan received less than the prescribed dose to achieve the organ at risk tolerance doses. Table 1 summarizes the results for target coverage and Table 2 summarizes the results for the OAR doses. Both tables show an average and standard deviation for the 16 patients with nasopharynx cancer. Dose reduction in OARs (cord, brain stem, optic chiasm, optice nerve and lens) was achieved with IMRT and 3DRT technique except contralateral parotid sparing was improved with IMRT than conformal

Table 1: Comparison of conformal and IMRT plans: CTV70, CTV63 and CTV56 volume receiving 95% of the prescribed dose for16 nasophyrnex patient

target	conformal	IMRT	p-value
% CTV70 receiving 95% of the prescribed dose	95±0.1935	97± 0.2886	< 0.0001
% CTV63 receiving 95% of the prescribed dose	90± 1.237	95.5±0.8851	< 0.0001
% CTV56 receiving 95% of the prescribed dose	95±0.40	98±0.73	< 0.0001

Table 2:Comparison of conformal and IMRT plans: maximum dose to the spinal cord ,brain stem, optic nerve, lenses, optic chiasm and mean dose parotid volume for 16 nasophyrnex patient

structure	conformal	IMRT	p-value
Maximum dose % to the spinal cord	62± 1.298	59±2.100	0.0005
Maximum dose % to the brain stem	75±1.438	±1.699 61	< 0.0001
Maximum dose% to the Optic chiasm	67±3.671	2.13978	< 0.0001
Mean dose% to Lt parotid	±2.26481.5	27.8± 6.413	< 0.0001
Mean dose% to Rt parotid	80.6± 1.805	28± 5.788	< 0.0001
Maximum dose% to the Lens	2.3 ± 0.4422	6 ± 1.689	0.0048
Maximum dose % to the Optic nerve	50 ± 32.187	29± 15.738	0.0342

IMRT optimization with Xio system:

Defining the most effective technique for dose optimization according to the relation between target volume and OAR locations is the key of inverse treatment planning. The important task of dose optimization in IMRT is defining the dose constraints for all the defined volumes and this differs from treatment planning algorithm to other. Often, minimum, maximum, and goal doses are defined for all targets. For organ at risks OARs dose optimization maximum dose was specified for serial organs (Spinal cord), for parallel organs (Parroted) the mean dose which is represented by 3-point DVH dose constraints was used for dose optimization. In theory, entire DVH distributions could be used. The inverse planning algorithm can assign power to doses outside these limits, which can be greater or smaller than simply the quadratic difference implied by the goal dose. For example, the cost of having a dose higher than the maximum specified for a given normal tissue could be the assignment of an extra weight. Most inverse planning algorithms have a simple quadratic dose difference for each structure, with weighting factors that can be adjusted by the planner. This can be implemented by giving relative importance factors to each volume. For example, the objective function (OF) can be written as

$$OF = \sum_n w_n, [D_o(X_n Y_n Z_n) - D(X_n Y_n Z_n)]^2$$

where, D_o is the prescribed dose, D is the calculated dose at point n, and w is the weighting factor for the structure that contains point n.

The results showed that power (penalty) and weight used to improve target volume distribution and reduce the hot area differed from site to another according to prescription dose, volume of target and surrounding OARs. Head and neck table 3. In all cases the minimum dose to CTV should be seated as the prescribed dose and the maximum dose to CTV should be higher than the prescribed dose by about 2-3%.

Most OARs should have high Power to achieve reduced dose as much as possible and keep these organs within tolerance table 4. to keep the doses received by OARs within tolerance the dose constrains showed was lower than the tolerance by about 20%, for example, to achieve mean dose to parotid of 26 Gy the mean dose of DVH of the dose constrains should be 19-21Gy, for the brain stem to achieve max dose 54Gy the maximum dose constrains should be 45-47Gy .

Table 3: power and weight needed for Clinical target volume (CTV) dose optimization.

Tumor Site	Power for minimum dose	Weight for minimum dose	Power for maximum dose	Weight for maximum dose
Head & neck	3.3±0.15	500	3.4±0.12	300

Table 4: power and weight needed for OARs in nasopharnex

organ	Power	Weight
Brain stem	3.5	100
Optic nerve	3.4	100
lens	3.4	100
parotid	2.8-3.3	100
cord	3	100

Dose Optimization using beam orientations and number of beams.

Optimization using beam orientations

Although the inverse planning can partially compensate for a relatively poor choice of beam directions by the ability to modulate the beam intensity within a field elsewhere the good choice of the beam directions can facilitate the optimization process. For head and neck cases table 5 showed that the optimal gantry angle degrees were 180°, 230°, 280°, 320°, 30°, 80° and 130° which mean that starting with a direct posterior beam for patients in supine position allowed better control of dose distributions in target regions close to the sensitive structure brain stem and spinal cord, decreasing the dose which received to these organs at risk, at the same time give better coverage for the CTV.

Table 5: IMRT beam arrangements used in the study of dose distributions.

Site of tumor	Gantry angles equispace arrangements		
	180°, 230°, 280°, 320°, 30°, 80° and 130°	0°, 50°, 100°, 150°, 200°, 250°, 300°	20°, 70°, 120°, 190° 220°, 270°, 320°
Head and Neck			
% CTV70 receiving 95% of the prescribed dose	97	95.6	95.7
% CTV63 receiving 95% of the prescribed dose	97	94	92.6
% CTV56 receiving 95% of the prescribed dose.	95	93	93.3
Max dose % for brain stem	74	77	77
Max dose % for cord	64	66	67
Mean dose % for Rt. parotid	31	34	34
Mean dose % for Lt. parotid	34	36	36

Optimization using Number of beams:

The choice of treatment fields also affects the optimized dose distribution, particularly for concave targets. Increasing the number of fields may lead to an acceptable plan when one is not physically possible with fewer beams. For complex shapes of tumor volume and sensitive organs very near to target and higher prescribed dose such as head and neck, the higher numbers of beams > five beams was optimal option, Table 6: shows the effect of increasing the number of treatment fields from 5 to 9 for the PTV and OARs.

Table 6: compare number of beams according to CTV coverage and OARs sparing.

	5beams	7 beams	9 beams
Head &neck			
% CTV70 receiving 95% of the prescribed dose	95	95.7	96
% CTV63 receiving 95% of the prescribed dose	94.7	96.9	96.9
% CTV56 receiving 95% of the prescribed dose	95.5	96.5	97
Maximum dose% to spinal cord	64	64	64
Maximum dose% to optic chiasm	75	74	74
Mean dose % to parotid	34	31	31

DISCUSSION

The data presented are able to support that IMRT is a safe and feasible modality in the treatment of complex-shaped NPC in the head and neck. By using IMRT, high doses in the GTV and PTV can be achieved not only was a better dose distribution in CTV found but also better critical structure sparing was achieved with IMRT compared with 3DRT technique. Among several critical tissues exposed when head and neck cancers are treated the parotid glands were of utmost interest in our study. Using 3DRT and conventional planning techniques we would not be able to deliver the prescribed dose to the target volume without risking complications related to irradiation of critical structures. High dose delivered to parotid glands and spinal cords can lead to acute and late complications in patients irradiated in the head and neck region. The biggest profit from IMRT technique was gained in the parotid glands. In the spinal cord results obtained with IMRT and 3DRT were comparable.

Although many steps in the planning process for IMRT treatments are similar to those for 3-D conformal treatments, the inverse planning optimization process differs significantly and requires planners to develop new technical skills and ways of thinking about treatment planning. This method of planning may not be intuitive and may take longer time than 3-D conformal planning but if the planners developed constraint templates and understood the objective function and so the optimal use of the optimization tools for each tumor site, IMRT planning will become routine and can normally be completed in approximately the same time as 3-D conformal plans.

The results have indicated that, in general, prescribed doses must be more stringent than the desired clinical result and that the patient's anatomy, in particular, the proximity of the critical normal tissues to the target, must be considered when setting the optimization parameters tables 3 and 4.

High dose delivered to parotid glands and spinal cords can lead to acute and late complications in patients irradiated in the head and neck region by using 3DRT technique not be able to deliver the prescribed dose to the target volume without risking complications related to irradiation of critical structures. Additional the course of treatment performed by more than one phase using electron fields as supplement in phase 2 and 3 to treat the lymph nodes in the neck posterior without increase the dose to spare spinal cord increasing errors results in a match between photon and electron fields. Simultaneous integrated boost technique was applied in the study and it succeed to avoid the heterogeneous dose distributions which could appear for the targets in the boost courses to raise some issue about local control probability.

CONCLUSION

Simultaneous integrated boost IMRT achieved comparable plans to 3D-CRT in complex head and neck case IMRT results in improved dose distribution within CTV compared to 3DRT. At the same time is also possible to reduce the dose to the organ at risk, especially the parotid, brain stem and spinal cord.

REFERENCES

1.S.A. Syam Kumar, Nagarajan Vivekanandan, Padmanaban Sriram, A study on conventional IMRT and RapidArc treatment planning techniques for head and neck cancers, reports of practical oncology and radiotherapy 1 7 (2 0 1 2) 168–175

2.John Waldrona, Mo Mo Tina, Anne Kellerb, Cheemun Lumb, Barbara Jappc, Susanna Sellmanna,Monique van Prooijenc, Leah Gittermana, Ralph Blendb, David Paynea, Fei-Fei Liua,Padraig Wardea, Bernard Cummingsa, Melania Pintilied, Brian O'Sullivan Limitation of conventional two dimensional radiation therapy planning in nasopharyngeal carcinoma Radiotherapy and Oncology 68 (2003) 153–161

3. L. Cozzi, A. Fogliata, A. Lomax, and A. Bolsi, 2001. A treatment planning comparison of 3D conformal therapy, intensity modulated photon therapy and proton therapy for treatment of advanced head and neck tumors. Radiother Oncology 61, 287–297

4. W. De Neve 1999. Clinical delivery of intensity modulated conformal radiotherapy for relapsed or second-primary head and cancer using a multileaf collimator with dynamic control. Radiother Oncology 50, 301–314

5. C. W. Hurkmans, B. C. J. Cho, E. Damen, L. Zijp, and B. J. Mijnheer,2002. Reduction of cardiac and lung complications probabilities after breast irradiation using conformal radiotherapy with or without intensity modulation. Radiother Oncology, 62, 163–171

6. D. Verellen, N. Linthout, D. V. D. Berge, A. Bel, and G. Storme,1997. Initial experience with intensity modulated conformal radiotherapy for treatment of the head and neck region. Int. J. Radiation Oncology Biology Physics, 39, 99–114.

7. Eisbruch A, Ship JA, Martel MK, et al. Parotid gland sparing in patients undergoing bilateral head and neck irradiation: techniques and early results. Int J Radiat Oncol Biol Phys 1996; 36:469–80.

8. Ozyigit G, Yang T, Chao KS. Intensity-modulated radiation therapy for head and neck cancer. Curr Treat Options Oncol 2004; 5:3–9.

9. M. Johnston , S. Clifford *, R. Bromley *y, M. Back *, L. Oliver *y, T. Eade *Volumetric-modulated Arc Therapy in Head and Neck Radiotherapy: A Planning Comparison using Simultaneous Integrated Boost for Nasopharynx and Oropharynx Carcinoma Clinical Oncology xxx (2011) 1e9

10. Thomas G Wendt*1, Nasrin Abbasi-Senger1, Henning Salz2, Ines Pinquart1,Sven Koscielny3, Susi-Marie Przetak1 and Tilo Wiezorek2 3D-conformal-intensity modulated radiotherapy with

compensators for head and neck cancer: clinical results of normal tissue sparing, Radiation Oncology 2006, 1:18