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DOSIMETRIC INFLUENCE OF SYSTEMATIC POSITIONING ERRORS BY INDUCING A 3 mm BIAXIAL SHIFT IN A CASE OF LOCALLY ADVANCED NASOPHARYNX CANCER TREATED WITH EXTERNAL BEAM RADIOTHERAPY

BY

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Abstract. Head & neck malignancy are cancers where radiotherapy is often the main method of treatment especially in advanced cases outdated for surgery. To analyze the dosimetric effects of a biaxial 3 mm position change from isocenter a + 3 mm shift on the X and Y axes was applied. Doses received by OAR (organs at risk) and target volumes treated with sequential boost were evaluated - PTV-T (target volume of the primary tumor) which received 70Gy/35 fractions, PTV-N66 witch received 66Gy/33 fractions and PTV-N50 irradiated with 50Gy/25 fractions. Evaluation of D_{max}, D_{min} and D_{mean} was done both for target volumes and for OAR’s before and after applying the biaxial shift for 3D-CRT(3D-conformal) plans and IMRT (intensity modulated radiation therapy) and VMAT (volumetric modulated arc therapy) alternative plans. The

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dose-volume effect was significant only for phase II and phase III. In case of some OAR's for 3D-CRT technique the maximum recommended dose was exceeded.

Keywords: radiotherapy; IMRT; VMAT; OAR.

1. Introduction

Head & neck malignancies are cancers for which radiotherapy is one of the main methods of treatment especially in advanced cases when surgical approach is impossible. For advanced nasopharyngeal cancer, surgical resection is almost impossible, concurrent radio-chemotherapy being the standard treatment. Surgery remains reserved for selective neck dissection in cases of persistent or recurrent nodal disease. High toxicity is one of the problems associated to conventional radiotherapy. IMRT technique provides better OAR protection (Fig. 1).

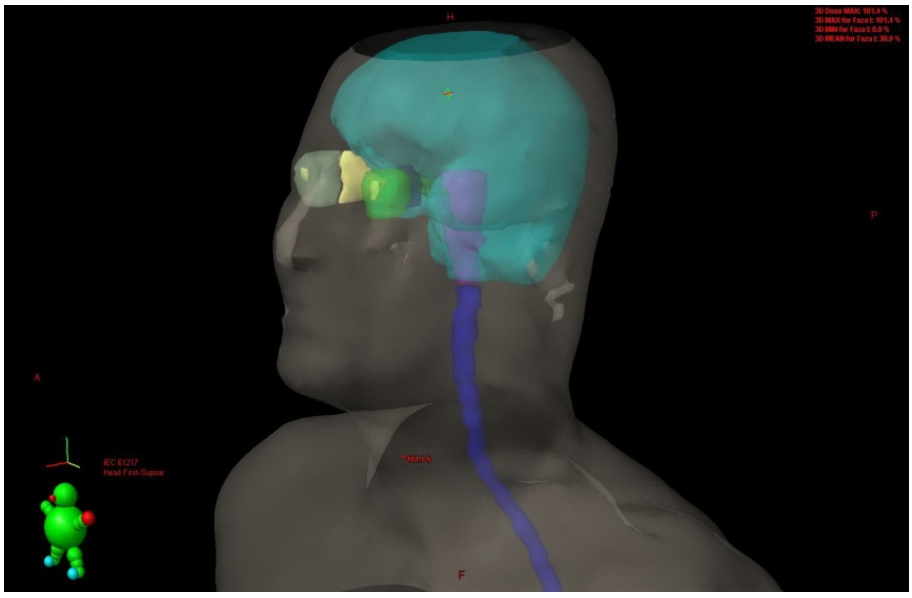

Fig. 1 – 3D reconstruction of organs at risk (OAR)
in nasopharynx radiotherapy.

Associated with a high coverage of target volume (Fig. 2) and a higher dose gradient. The presence of volumes receiving high doses in the immediate vicinity of protected tissues involves an increased risk of errors.

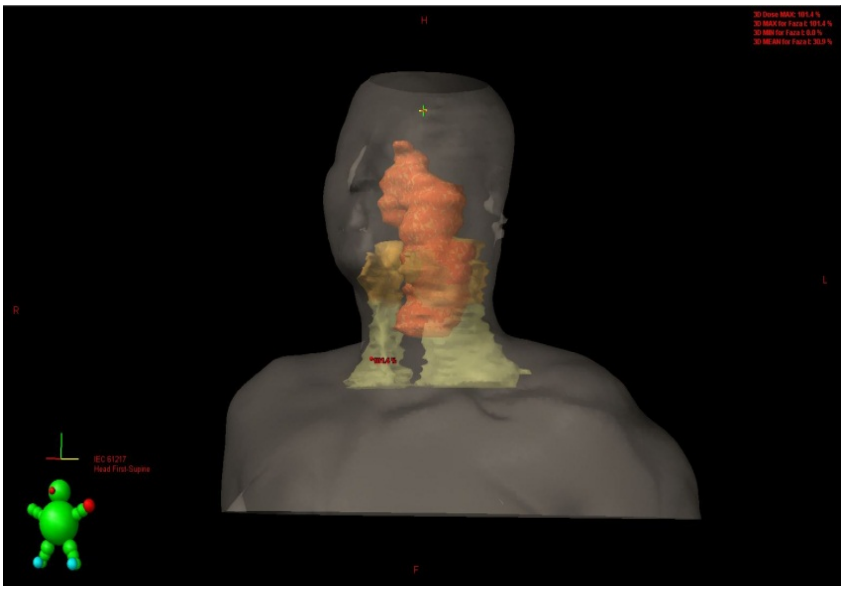

Fig. 2 – 3D reconstruction of target volumes PTV-T (red), PTV-N66 (magenta), PTV-N50 (Yellow).

Usage of CT simulation, orthogonal kV imaging systems for patient positioning and thermoplastic mask decreases the risk of random errors between each fraction. A calibration error of the treatment table or positioning lasers can induce a systematic error with unpredictable consequences for the treatment. To analyze the consequences of such an error a + 3 mm shift on X and Y axes was introduced, then recalculating being executed without 3D-CRT, IMRT and VMAT plans optimization. Dosimetric parameters D_{max}, D_{min} and D_{mean} for target volumes (each phase) and OARs were analyzed comparatively in absolute and relative values (Hong *et al*., 2005; Park and Park, 2016; Yan *et al*., 2013; Iancu and Iancu, 2004).

2. Results

For all techniques 3D-CRT, IMRT, VMAT significant decrease of D_{min} (29.55%, 21.62%, 27.20%) for the phase III of the sequential boost treatment plan is observed in case of 3 mm biaxial shift application to isocenter. In the case of absolute dose delivered by IMRT technique, lower D_{min} value associated with shift effect increases the risk of “cold spots”. The same phenomenon can be observed in the case of phase II, the minimum dose in phase I being less influenced in all situations (see Table 1).

Table 1

Relative Variation of D_{min}, D_{max} and D_{mean} Received by the Target Volumes and Organs at Risk by Applying a + 3 mm Biaxially Isocentric Shift

D_{MIN}	Radiotherapy Technique (Absolute Dose)						Radiotherapy Technique (Dose Change)		
Phases and OARs	3D-CRT(cGy)	3D-CRT-SHIFT(cGy)	IMRT(cGy)	IMRT-SHIFT(cGy)	VMAT(cGy)	VMAT-SHIFT(cGy)	3D-CRT (%)	IMRT (%)	VMAT (%)
Phase III	5725.00	4033.30	3734.90	2927.40	6295.20	4583.00	-29.55	-21.62	-27.20
Phase II	3746.10	3400.40	3288.80	2583.70	5138.70	3931.90	-9.23	-21.44	-23.48
Phase I	2860.20	3106.80	5927.00	4926.80	3008.10	3060.00	8.62	-16.88	1.73
Left parotid	3345.40	3370.80	1390.40	1548.40	2589.70	2685.30	0.76	11.36	3.69
Right parotid	2824.90	2737.60	2095.10	1995.90	2517.40	2312.60	-3.09	-4.73	-8.14
Brain	27.30	26.20	13.00	12.10	15.30	14.30	-4.03	-6.92	-6.54
Brain stem	200.70	183.90	167.80	150.90	264.90	210.30	-8.37	-10.07	-20.61
Spinal cord	22.70	23.90	8.90	9.90	12.90	14.20	5.29	11.24	10.08
Left optic nerve	190.90	179.10	144.80	134.60	367.20	318.20	-6.18	-7.04	-13.34
Optic chiasma	293.80	262.90	246.00	216.10	160.20	146.10	-10.52	-12.15	-8.80
Right optic nerve	182.00	168.80	129.10	117.70	148.60	132.30	-7.25	-8.83	-10.97
Left lens	184.10	173.20	147.00	138.30	163.90	151.90	-5.92	-5.92	-7.32
Right lens	173.90	162.80	119.50	110.70	135.20	123.90	-6.38	-7.36	-8.36

D_{MAX}	Radiotherapy Technique (Absolute Dose)						Radiotherapy Technique (Dose Change)		
Phases and OARs	3D-CRT(cGy)	3D-CRT-SHIFT(cGy)	IMRT(cGy)	IMRT-SHIFT(cGy)	VMAT(cGy)	VMAT-SHIFT(cGy)	3D-CRT (%)	IMRT (%)	VMAT (%)
Phase III	7564.70	7690.90	7441.00	7566.80	7427.70	7590.00	1.67	1.69	2.19
Phase II	7564.70	7690.90	7441.00	7566.80	7427.70	7590.00	1.67	1.69	2.19
Phase I	7564.70	7690.90	7416.90	7560.40	7427.70	7590.00	1.67	1.93	2.19
Left parotid	7242.80	7548.20	7326.30	7478.60	7077.20	7291.50	4.22	2.08	3.03
Right parotid	7177.20	7205.00	7218.30	7317.00	7047.60	7009.80	0.39	1.37	-0.54
Brain	6919.20	6642.30	6128.80	5901.40	6269.60	6229.90	-4.00	-3.71	-0.63
Brain stem	6518.70	6476.30	5498.80	5451.10	5609.30	5589.20	-0.65	-0.87	-0.36
Spinal cord	4498.00	5118.20	4364.40	4547.50	4254.40	4566.30	13.79	4.20	7.33
Left optic nerve	447.90	402.10	414.70	371.60	600.70	538.90	-10.23	-10.39	-10.29
Optic chiasma	444.60	381.80	402.90	338.60	509.10	454.30	-14.13	-15.96	-10.76
Right optic nerve	416.90	365.40	333.40	289.10	476.20	411.00	-12.35	-13.29	-13.69
Left lens	215.90	204.70	176.00	165.90	202.60	187.30	-5.19	-5.74	-7.55
Right lens	202.00	188.70	145.10	135.40	171.50	155.40	-6.58	-6.69	-9.39

D_{MEAN}	Radiotherapy Technique (Absolute Dose)						Radiotherapy Technique (Dose Change)		
Phases and OARs	3D-CRT(cGy)	3D-CRT-SHIFT(cGy)	IMRT(cGy)	IMRT-SHIFT(cGy)	VMAT(cGy)	VMAT-SHIFT(cGy)	3D-CRT (%)	IMRT (%)	VMAT (%)
Phase III	7094.30	7100.50	6798.70	6831.00	7021.10	7034.80	0.09	0.48	0.20
Phase II	6902.90	6932.60	6213.90	6248.50	6803.80	6835.80	0.43	0.56	0.47
Phase I	6282.00	6316.20	7004.50	7039.60	6217.10	6251.50	0.54	0.50	0.55
Left parotid	5837.20	5913.00	4386.80	4624.40	4577.70	4800.60	1.30	5.42	4.87
Right parotid	5794.90	5348.40	4573.10	4156.40	4943.30	4439.80	-7.71	-9.11	-10.19
Brain	318.30	273.10	315.50	266.70	349.40	303.30	-14.20	-15.47	-13.19
Brain stem	1654.90	1443.60	1585.80	1361.50	1736.30	1525.30	-12.77	-14.14	-12.15
Spinal cord	2336.10	2423.30	2129.90	2217.90	1976.40	2078.60	3.73	4.13	5.17
Left optic nerve	304.40	279.20	258.50	235.00	473.80	417.60	-8.28	-9.09	-11.86
Optic chiasma	362.70	318.60	315.80	273.00	318.20	287.80	-12.16	-13.55	-9.55
Right optic nerve	294.90	266.30	231.20	206.90	305.00	268.40	-9.70	-10.51	-12.00
Left lens	200.10	188.60	160.30	151.10	182.20	168.30	-5.75	-5.74	-7.63
Right lens	188.60	176.30	133.30	124.10	154.20	140.90	-6.52	-6.90	-8.63

D_{max} is less modified (minor increase) for all techniques without significant predictable clinical consequences. Also D_{mean} variations are insignificant for phase III using inverse planning techniques compared to 3D-CRT technique. For phases II and III D_{mean} increases are approximately equal in all situations by applying isocenter shift (about 0.5%) (see Table 1).

The consequences of applying biaxial shift for OAR is the D_{max} decrease in most organs excepting left parotid and spinal cord. For all techniques 3D-CRT, IMRT, VMAT left parotid D_{max} increases with 4.22%, 2.08%, 3.03% and D_{mean} increases with 1.30%, 5.42% and 4.87%. For spinal cord D_{max} increases with 13.79%, 4.20% and 7.33%, D_{mean} increases with 3.73%, 4.13% and 5.17%, but only for 3D-CRT plan (D_{max} = 51.18Gy) the absolute dose exceeds upper limit recommendation of Quantec (see Table 1).

3. Discussion

The use of modern radiotherapy methods has reduced the volume exposed to large doses of radiation therapy, improving treatment accuracy, reducing normal tissue toxicity related to irradiation, increased importance given to accurate position verification and correction before delivering radiotherapy. IGRT enables evaluation of geometry for treatment delivery providing a method by which deviations from the original plan of anatomy are determined and this information is used to correct the dosimetric parameters. Bony landmarks were easy to detect and correct and the table shifts for correction of setup deviations could be automatically calculated. An error in radiotherapy is any deviation from intended or planned treatment (Hong *et al*., 2005; Thilmann *et al*., 2006; Dawson and Jaffray, 2007).

The risk of a systematic error is low but the clinical consequences can be unpredictable if the error is not corrected before or during treatment. Decrease of D_{min} in phase III corresponds to target volumes that will receive the entire dose of 70Gy/35 fractions increases the number of cold spots associated with risk of under-dosage in primary tumor volume. The association between a D_{min} decreased in absolute and relative decrease of D_{min} by applying "simulated error", the presence of "cold spots" in a radio-resistant hypoxic zone may be a factor associated with the presence of a residual tumor at the end of treatment. In this case IMRT technique is associated with a higher risk of under-dosage for target volume of primary tumors of the nasopharynx than 3D-CRT and VMAT techniques. By applying the biaxial isocenter shift laterocervical nodal levels (PTV-N66) shows a lower risk of under-dosage than (PTV-T) and the dose effect to supraclavicular nodal (PTV-N50) level is insignificant (Fig. 2). The presence of clinically detectable lymph nodes with a good response to therapy or a significant patient weight loss resulting in neck circumference reduction associated with isocentric shift can bring the skin in the build-up dose area, especially for the case of IMRT technique with more tangential fields (Iancu and Iancu, 2004; Kaur *et al*., 2016; Liu *et al*., 2016).

4. Conclusions

A systematic error of + 3 mm biaxial shift applied to isocenter has no severe consequences on the quality of treatment of nasopharyngeal primary tumor but may result in under-dosage in laterocervical nodal volumes. Adding a random error to the induced systematic error can amplify or reduce the dosimetric effects. In the case of exceeding the value of the total error beyond

the distance limit that manifests intense dose gradient for IMRT and VMAT methods there is a major possibility to irradiation with major dosimetric consequences for the target volumes and normal tissue. Immobilization systems (thermoplastic masks), IG systems and an accurate calibration of the treatment table and positioning lasers ensure the quality of treatment.

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EFECTUL DOZIMETRIC AL ERORILOR SISTEMATICE DE POZIȚIONARE PRIN INDUCEREA ARTIFICIALĂ A UNEI DEPLASĂRI BIAXIALE DE 3 mm A MESEI DE TRATAMENT ÎN RADIOTERAPIA EXTERNĂ A CANCERULUI DE RINOFARINGE LOCAL AVANSAT

(Rezumat)

Cancerele sferei ORL sunt patologii în care radioterapia este de multe ori metoda principală de tratament, în special în cazurile avansate, depășite chirurgical. Analizăm efectul dozimetric a unei deplasări biaxile, de 3 mm, asupra izocentrului, aplicând un shift pe axele x și y de + 3 mm și evaluând dozele la organele de risc și în volumele țintă PTV-T (volumul țintă al tumorii primare), care a primit o doză de 70Gy

în 35 fracțiuni (faza I), PTV- N66 (faza II) și PTV-N50 (faza III) pentru ariile gaglionare laterocervicale și supraclaviculare iradiate cu 66, respectiv 50Gy în 33 și 25 fracțiuni, prin tehnica boost-ului secvențial. Evaluarea parametrilor dozimetrici Dmax, Dmean și Dmin s-a făcut atât pentru volumele țintă cât și pentru OAR (organele de risc) înainte și după aplicarea shiftului pentru planurile 3D-CRT (3D conformațional) și pe planurile alternative IMRT (radioterapie cu intensitate modulată) și VMAT (radioterapie rotațională cu intensitate modulată). Efectul asupra volumelor țintă ca distribuție a dozei a fost semnificativ doar în fazele II și III. În cazul OAR, prin tehnica 3D, în urma shiftului s-a depășit doza maximă recomandată de ghidul dozimetric QUANTEC.