COMPARISON OF 3D-CRT AND IMRT PLANS BASED RADIOTHERAPY FOR DIFFERENT TREATMENT SITES

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Abstract

In this study, we perform a dose-volume histogram (DVH) comparative analysis for three-dimensional conformal radiotherapy (3DCRT) plans using XiO® treatment planning system (TPS) for three-dimensional conformal radiation therapy (3DCRT) and Monaco TPS for intensity-modulated radiotherapy (IMRT), with linear accelerator (Elekta Synergy), by analyzing dose distribution in target volumes and organs at risk. The aim of the study was to determine which patients would benefit most from the IMRT based delivery. Ten patient's plans that were previously planned with curative intend on XiO® TPS, were re-planned with IMRT techniques in Monaco TPS that recently were installed in the clinic. Step and shoot techniques with Monte Carlo algorithm has been used for IMRT plans. The treatments were delivered by Synergy Platform (Elekta MLCi2) using 6, 10 and 18 MV energy. Target coverage was evaluated with the D_{95}, D_{min} and D_{max} for both methods and organs-at-risk (OAR) was evaluated according QUANTEC. From the DVH comparison of ten different sites (Head & Neck, Breast + Subclavicular, Lungs, Prostate, Rectum Region), respectively 95% coverage of PTV for all study patients with 3D CRT is 92.99% and with IMRT is 97.41%. Doses to OARs in average have better sparing with IMRT plans than 3D-CRT plans.

Key words: XiO TPS, Monaco TPS, DVH, Linac, IMRT, 3D CRT, OAR.

Introduction

The transition from three-dimensional conformal radiotherapy (3DCRT) to intensity modulated radiotherapy (IMRT) requires implementation of complex advanced dosimetry, fully commissioned treatment planning system (TPS) and modern Linear Accelerator as well high professional staff.

In Radiotherapy Department there are two linear accelerators Elekta Synergy operational for patient treatments. Installation of the second Linear accelerator, Elekta synergy with cone beam CT (XVI) and three energies (6MV, 10MV and 18 MV), and multileaf collimator (MLC) with 1 cm leaf width at the isocenter, gave us the possibility of using the highest standard of cancer treatment in our department using IMRT technique. This technique has increased the complexity of radiotherapy treatment planning while improving the dose conformal to the target and dose reduction to the normal structures surrounding the target.

The present study is aimed at comparatively analyzing radiation doses in target volume (Planning Target Volume - PTV) and organs at risk (OAR) for patients with different diagnosis using 3DCRT and IMRT techniques.

Methods and materials

Ten patients, with different diagnosis and stage, were planned using both techniques 3DCRT (XiO) and IMRT (Monaco). For each patient, 3DCRT optimum plan were created in XiO treatment planning system for treatment sites: Head& Neck, Breast + Subclavicular, Lung, Prostate and Rectum. All patients previously planned with 3DCRT in XiO TPS have been transferred to Monaco TPS. The treatment plans were redone in Monaco TPS with IMRT technique using the Step and Shoot mode. The PTV included the same PTV used for the 3DCRT plans. An Elekta Synergy linear accelerator with three photon energy of (6/10/18) MV was used for all cases.

All patients were scanned in Computed Tomography (CT) (Philips Big Bore) with 3 mm slice thickness. All sets of CT slices were transferred via DICOM to Focal system.

For each clinical case, the clinical target volume (Clinical Target Volume-CTV), planning target volume (PTV) and organs at risk (Organs At Risk OAR) has been delineated by the physician on axial slices and was transferred to the treatment planning system (TPS).

Treatment planning systems

Treatment planning system XiO (CMS) software was used to calculate dose plan for all patients with three-dimensional conformal radiotherapy (3DCRT). For 3DCRT we use Field-in-Field techniques were the beam parameters are manually adjusted to achieve a good dose distribution to the PTV and at the same time to spare the OARs from receiving high doses. All forward plans were produced by experienced physicists who are fully trained in the XiO TPS.

Treatment planning system Monaco with Monte Carlo algorithm was used to calculate dose for all patients with Intensity-modulated radiation therapy (IMRT). In this technique, after the beams are set, the inverse IMRT planning was used to make an automatic segmentation of all beams using the multileaf collimator (Multi Leaf Collimators - MLC) for dose distribution in accordance with clinical objectives (9).

Beams Arrangement

With 3DCRT technique we used different number and directions of photon fields according to the position and size of the tumor as well to avoid as much as possible the organ at risk (OARs). An aperture 0.5 up to 0.8cm MLC margin around PTV was used in treatments fields, according to the treatment sites. Three to six main fields were used to plan each patient using MLCs to cover the PTV and to spare nearby OARs. Small additional fields were used in all plans to conform the dose distributions. The beam angles, wedge angles, and beam weighting were chosen to optimize PTV coverage, while minimizing exposure to the OARs. Normalization point has been choosen to have the best dose distribution.

With IMRT technique we used Step and Shoot mode for patient's plans. The dose calculation algorithm used is "Monte Carlo". An optimization with 150-250 segments was applied with minimum 0.5 cm field size in all cases. Six up to nine treatment fields were used in equal space angels, according to the treatment sites. The beams are optimized to deliver a high dose to the target volume and low dose to the surrounding OARs. PTV was prescribed to be covered by 95% of the dose and the OAR to respect the limits according to the QUANTEC recommendation for IMRT plans (10).

Evaluation of the Treatment Plans

The evaluation of the treatment plans for both techniques has been done by many tools; by analyzing visual isodose distributions slice-by slice of the treatment plans; dose volume histogram (Dose Volume Histogram - DVH) to evaluate 95% coverage of PTV and CTV; dose max and min of PTV, CTV and dose of OAR for all cases according to QUANTEC limits for IMRT and 3DCRT (12).

RESULTS

3D CRT versus IMRT Radiotherapy Planning Techniques

Head & Neck cases

In this study, we have compared two cases with Head and Neck cancer. In both cases, the doctor contours PTV, CTV and OARs. In our department, mostly of the Head and Neck cancer is treated with sequential fractionated radiotherapy dose. In our case, we have compared only the first phase were the prescribed dose was 50 Gy in 25 fractions.

3D-CRT technique**;** four main fields (AP-PA; 2 oblique wedged fields) and 4 other addition small fields with combination of 6MV and 10MV energy have been used in this case. An automatic aperture of multileaf collimator of 0.5cm around PTV was used.

IMRT technique**;** nine equidistance fields with 6MV energies have been used in this case. After optimization, the optimum plan has been chosen were PTVs coverage and OARs having better results (4).

Statistics; Dose volume histograms of the PTV, CTV and organs at risk of the 3DCRT and IMRT plans parameters obtained from the same patient were compared.

The target coverage was evaluated in the PTV, and CTV obtaining the parameters for each of the treatment modalities: minimal, maximum and 95% coverage of the volume (CTV_{95}, PTV_{95}), which shown in **Table1**.

Table 1

		XIO				MONACO		
		Min	**Max**	**95%**		**Min**	**Max**	**95%**
Case1	PTV	1450.7	5357	**92**	PTV	3136.6	5614.2	**99.6**
	CTV	3305.8	5357	**98.7**	CTV	4357.9	5602.2	**99.9**
Case2	PTV	2262.2	5388.5	**89.7**	PTV	3731.8	5573.3	**99.3**
	CTV	3856.3	5388.5	**96.1**	CTV	4557.3	5564.9	**99.9**

Fig.1. showed the isodose line distribution in the treatment target volume (PTV), beams arrangements for PTV, CTV and OARs for the same patient plans using XiO TPS with 3DCRT techniques and using Monaco TPS with IMRT techniques.

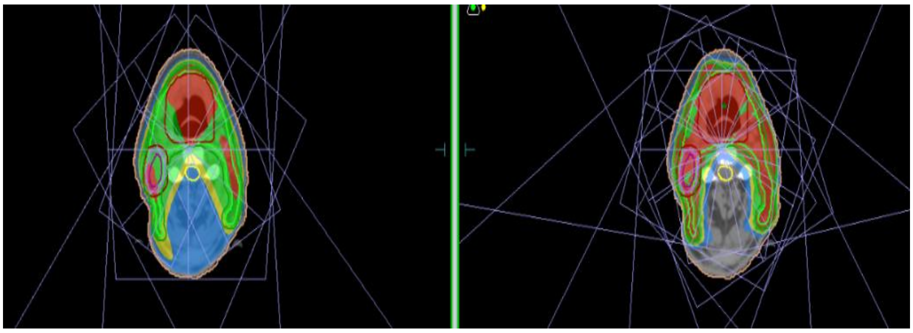

Fig.1 left (XiO); right (Monaco)

From DVH analysis of two selected patients, IMRT plans were associated with lower radiation exposure to the mean dose of (right and left) parotids. The average values of **mean** dose for parotids, in both cases, were 20Gy with IMRT versus 34.8Gy with 3D-CRT plan. **Maximum** dose of Spinal Cord was lower with IMRT, respectively 37.87Gy with IMRT versus 48 Gy with 3DCRT. **95%** of PTV coverage was 99% with IMRT vs 90.8% with 3DCRT.

Breast plus subclavicular cases

In this study, we have compared two cases with breast cancer. In both cases, the doctor contours both breast and subclavicular region. In our department, mostly of the breast cancer is treated with hypofractionated radiation therapy. The prescribed total dose was 40.05 Gy in 15 fractions.

3DCRT; Two tangential opposed beams and three to four other addition fields were used for breast target, and 2 opposed fields (AP-PA) for subclavicular region. The beam angles, wedge angles, and beam weighting were chosen to optimize coverage of the PTV, while minimizing exposure to the lung, heart and contralateral breast (1).

IMRT Technique; Six fields with 6MV energy have been created for PTV-ss. PTVbreast, PTVsupra and OAR are put under optimizing procedure. After optimization, the optimum plan has been chosen were PTVs coverage and OARs having better results.

Statistics; Dose volume histogram of the PTV, CTV and organs at risk of the 3DCRT and IMRT plans parameters obtained from the same patient were compared. The target coverage and dose distribution were evaluated in the PTV, and CTV (breast and supra) obtaining the following parameters for: minimal, maximum and 95% coverage of the volume (CTV_{95}, PTV_{95}) for breast and subclavicular region.

Table.2

		XIO				MONACO		
		Min	**Max**	**95%**		**Min**	**Max**	**95%**
Mamme1	PTV	1597.2	4303.4	**91.1**	PTV	2435.9	4474.7	**96.5**
	CTV	1878.1	4303.4	**95.33**	CTV	3356.7	4497.1	**98.9**
Mamme2	PTV	1473	4290.1	**89**	PTV	3389.3	4474	**98**
	CTV	2597.3	4290.1	**96**	CTV	3629.2	4474	**99**
		XIO				**MONACO**		
		Min	**Max**	**95%**		**Min**	**Max**	**95%**
Supra1	PTV	2947	4293.7	**85**	PTV	3635.1	4259.4	**99.5**
	CTV	3347.6	4281.5	**89.9**	CTV	3735.4	4259.4	**100**
Supra2	PTV	2633.9	4269.3	**85**	PTV	3669.2	4226.7	**98.51**
	CTV	3495.5	4269.3	**95**	CTV	3723.2	4203.5	**100**

Fig.2. showed the isodose line distribution in the treatment target volume (PTV), beams arrangements for PTV, CTV and OARs for the same patient plans using XiO TPS with 3DCRT techniques and using Monaco TPS with IMRT techniques.

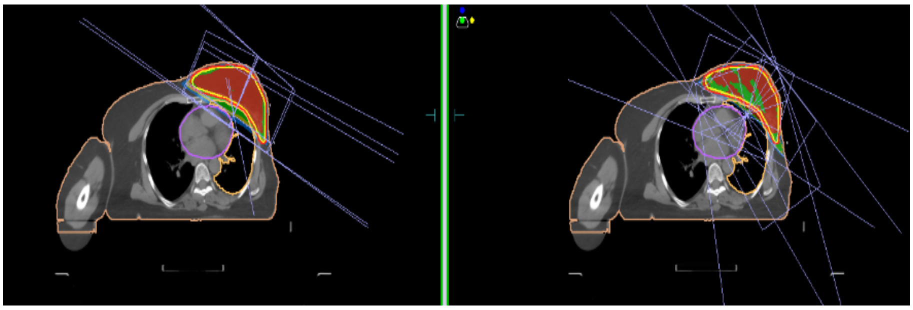

Fig.2 left (XiO); right (Monaco)

From DVH analysis of two selected patients, IMRT plans were associated with lower radiation exposure to the lungs. Statistically differences were noted in both lungs and Heart. The average values of **V20** in Lung, was 18.7% with IMRT versus 21.04% with 3D-CRT. Overall, heart doses were low with both IMRT and 3DCRT. Average of **Mean** heart dose was 3.89Gy with IMRT and 4.01Gy with 3DCRT. Humerus head archived lower dose with IMRT than 3D. **V5 Gy** was 26.315Gy with IMRT versus 33.27 Gy with 3D-CRT. **95%** of PTV coverage was 97% with IMRT vs 90% with 3DCRT.

LUNG CASES

In this study, we have compared two cases with lung cancer. In both cases, the doctor contours PTV, CTV and OARs. All plans (IMRT and 3DCRT) were standardized using a prescription dose of 60 Gy in 2-Gy fractions.

3DCRT technique**;** four main fields and other addition small fields, with combination of 6MV and 10MV energy have been used. An aperture of multileaf collimator of (0.5 up to 0.8) cm around PTV was used.

IMRT technique**;** Nine equidistance fields with 6MV energies have been used. PTV and all OARs were put under optimization process. After optimization, the optimum plan has been chosen were PTVs coverage and OARs having better results (6).

Statistics**;** Dose volume histograms of the PTV, CTV and OARs of the 3D-CRT and IMRT plans parameters obtained from the same patient were compared. The target dose distribution was evaluated in the PTV and CTV for each of the treatment modalities: minimal, maximum and 95% coverage of the volume (CTV_{95}, PTV_{95}), showed in table 3.

Table 3.

		XIO					**MONACO**			
		Min(cGy)	**Max**	**Mean**	**95%**		**Min**	**Max**	**Mean**	**95%**
Case1	PTV	5050	6367	6082	**96.6**	PTV	4880	6882	6028	**97**
	CTV	5642	6294	6077	**99.9**	CTV	5669	6446	6034	**99.9**
Case2	PTV	5103.5	6394.2	6051.3	**95.6**	PTV	4318.9	6742.2	6110.3	**96.2**
	CTV	5582.6	6385.2	6137.5	**99.9**	CTV	5713	6561.3	6228.1	**100**

Fig.3 showed the isodose line distribution in the treatment target volume (PTV), beams arrangements for PTV, CTV and OARs for the same patient plans using XiO TPS with 3DCRT techniques and using Monaco TPS with IMRT techniques.

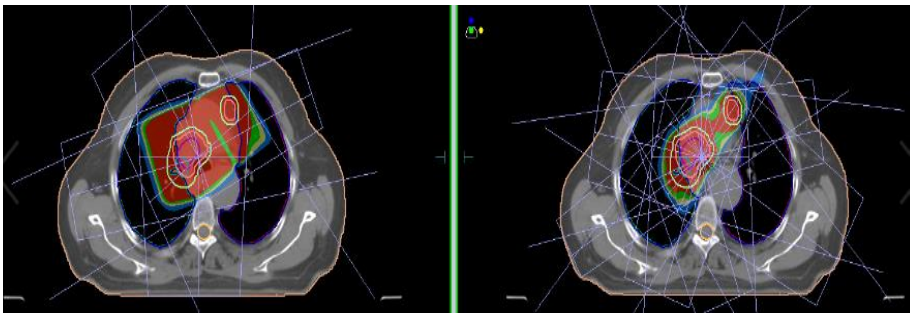

Fig.3 left (XiO); right (Monaco)

From DVH analysis of two selected patients we have the average values of **V20** in total Lung, was 30.32% with IMRT versus 43.2% with 3DCRT. Average of **Mean** dose heart dose was 13.9Gy with IMRT and 13.7Gy with 3D-CRT. **Maximum dose** of Spinal Cord was respectively 37.5Gy with IMRT versus 40 Gy with 3D-CRT. **95%** of PTV coverage was 95% with IMRT vs 97% with 3DCRT.

PROSTATE CASES

In this study, we have compared two cases with prostate cancer. In both cases, the doctor contour PTV, CTV and OARs. All plans (IMRT and 3DCRT) were standardized using a prescription dose of 50 Gy for one patient and 70Gy for the second patient.

3DCRT technique**;** four opposite fields with combination of 10MV and 18MV have been used for 3DCRT. Two other addition fields have been used for a better dose distribution and minimizing hot spots.

IMRT technique**;** nine equidistance fields with 10MV energies has been use. PTV and OAR were put under optimization process. After optimization, the optimum plan has been chosen were PTVs and OARs having better results (5).

Statistics; Dose volume histograms of the PTV, CTV and organs at risk of the 3DCRT and IMRT plans parameters of two selected patient, were compared. The target coverage and dose distribution were evaluated in the PTV, and CTV obtaining the following parameters: minimal, maximum and 95% coverage of target dose of PTV and CTV.

Tabela 4

		XIO				MONACO		
		Min	**Max**	**95%**		**Min**	**Max**	**95%**
Case 1	PTV	4169.4	5637.2	**93**	PTV	3419.3	5264.5	**97.22**
	CTV	4679.7	5637.2	**99.83**	CTV	4384.1	5264.5	**99.93**
Case 2	PTV	6149	7302	**98.28**	PTV	6177.5	7368	**99**
	CTV	6663	7302	**100**	CTV	6524.9	7358.1	**100**

Figure.4 showed the isodose line distribution in the treatment target volume (PTV), beams arrangements for PTV, CTV and OARs for the same patient plans using XiO TPS with 3DCRT techniques and using Monaco TPS with IMRT techniques.

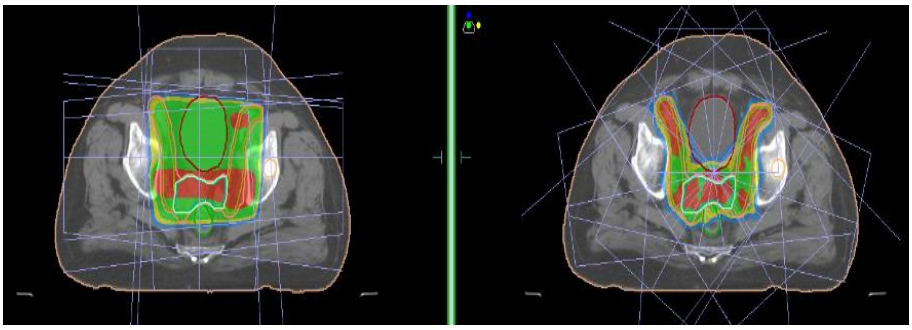

Fig.4 left (XiO); right (Monaco)

From DVH analysis of two selected patients we have: Rectum, in terms of **V65**, was 23.3% with IMRT versus 38% with 3DCRT plan. Bladder was better spared in IMRT plans in terms of **V65** were 23.9% with IMRT versus 55.66% with 3D-CRT plan. Average dose of **195cc** in Intestine was 16.3Gy with IMRT versus 20Gy with 3D-CRT plan. **95%** of PTV coverage was 98% with IMRT vs 95.6% with 3DCRT.

RECTUM CASES

In this study, we have compared two cases with Rectum cancer. In both cases, the doctor contour PTV, CTV and OARs. All plans (IMRT and 3D CRT) were standardized using a prescription dose of 45 Gy for each patient. 3DCRT technique**;** Three main fields with combination of 10MV and 18MV energies have been used for 3DCRT planning and two to three addition fields were used for a better dose distribution and minimizing hot spots.

IMRT technique; Seven coplanar equal-spaced fields were generated in this case. PTV and OAR were put under optimization process. After optimization, the optimum plan was chose were PTVs and OARs have better results (2).

Statistics; Dose volume histograms of the PTV, CTV and organs at risk of the 3DCRT and IMRT plans parameters obtained from the same patient were compared.

The target coverage and target dose distribution were evaluated in the PTV, and CTV obtaining the following parameters for each of the treatment modalities: minimal, maximum and 95% coverage of the volume (CTV_{95}, PTV_{95}), shown in table 5.

Tabela 5

		XIO				MONACO		
		Min	**Max**	**95%**		**Min**	**Max**	**95%**
Case1	PTV	3342.5	4861.9	92	PTV	3885.2	5023.4	98
	CTV	3879	4863.6	96	CTV	4089.2	5002.6	99
Case2	PTV	2867.1	4820.8	97	PTV	3891.5	4852.5	98.7
	CTV	3924.4	4820.8	99.3	CTV	4060.6	4852.5	99.6

Figure 5 showed the isodose line distribution in the treatment target volume (PTV), beams arrangements for PTV, CTV and OARs for the same patient plans using XiO TPS with 3DCRT techniques and using Monaco TPS with IMRT techniques.

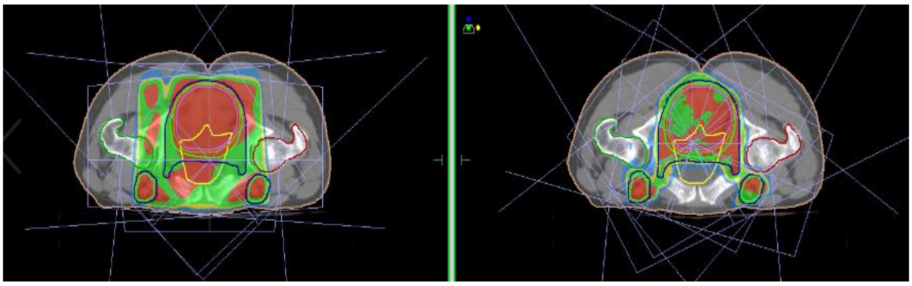

Fig.5 left (XiO); right (Monaco)

From DVH analysis of two selected patients we have: Bladder in terms of **V40**, respectively 68% with IMRT versus 99% with 3DCRT plan. Femoral Head was better spared in IMRT plans in terms of **5%** were 35.48Gy with IMRT versus 43.67Gy with 3D-CRT plan. Average dose of **195cc** in Intestine was 37.2Gy with IMRT versus 40.8Gy with 3DCRT plan. **95%** of PTV coverage was 98.3% with IMRT vs 94.5% with 3DCRT.

Conclusion

According to the results, we conclude that the IMRT planning technique achieved better dose coverage to the PTV and CTV for all cases in this study than the 3DCRT planning technique (7). According to OARs mainly of the organs at risk have better sparing with IMRT plans than 3DCRT but in some cases we have comparable values in both techniques. IMRT also require longer treatment times than 3DCRT, increasing the risk of patient movements.

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