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Comparison of conventional and 3D conformal treatments using linac energies for prostate cancer

S.A. Vaezzadeh[1*], M. Allahverdi[1,2], H.A. Nedaie[2], M. Aghili[2], M. Esfehani[2]

[1]Department of Medical Physics and Biomedical Engineering, Tehran University of Medical Sciences, Tehran, Iran
[2]Department of Radiotherapy – Oncology, Tehran University of Medical Sciences, Tehran, Iran

Background: To evaluate the dosimetric difference between conventional and three-dimensional conformal Radiotherapy (3D-CRT) using 6 and 18 MV X-ray photons. *Materials and Methods:* Computed tomography scans of 26 pelvic patients were acquired and transferred to the 3D treatment planning system. For each patient, 8 Conventional plans (3, 4, 5 and 6 Fields) and one 3D-CRT plan were prepared using 6 and 18 MV photon energies. The minimum dose (D_{min}), maximum dose (D_{max}) and mean dose (D_{mean}) to target (PTV) and organs at risk (OAR), Integral dose, Homogeneity Index and Conformity Index were compared for each plan. Also, Experimental measurements were performed using farmer ionization chamber on a patient based pelvic phantom. *Results:* On Average, six-field (6F1) plans, offer minimum dose to critical organs and sufficient dose to prostate. Increasing the beam energy lead to a decrease in D_{mean} of the bladder and femoral heads, as well as D_{max} of PTV. The CI and ID were decreased by 4% and 11% respectively with increasing the energy and the number of beams. Experimental measurements were also in good agreement with calculations. 3D-CRT reduced D_{mean} of bladder, rectum and femoral heads and also CI and ID were significantly improved by 44.6% and 30.8%, respectively. *Conclusion:* Increasing the photon energy and number of beams, improve the treatment parameters of bladder, femoral heads and PTV, except the rectum. 3D-CRT offered the most conformity in the delivery doses to the prostate while sparing dose to OARs, uninvolved structures with lower integral dose. **Iran. J. Radiat. Res., 2012; 10(3-4): 145-150**

Keywords: *Conventional, 3D-conformal radiotherapy, conformity index, integral dose, prostate cancer.*

INTRODUCTION

3D conformal radiation therapy (3D-CRT) is now routinely used at most radiotherapy centers. However, the complexity of such techniques leads to high maintenance costs and significant downtime.

There are several reports that have compared the difference between conventional and 3D-CRT techniques (1-6) or in various treatment plans (7-10) at different energies (7, 11, 12). A number of studies have used a series of new dosimetric parameters in their comparison such as Integral dose (ID), conformity index (CI) and homogeneity index (HI) (3, 11-16).

Despite of these reports, the choice of the optimal energy and treatment plans with respect to dose to organs at risk (OARs) such as rectum, bladder and femoral heads, and Planning target volume (PTV) using above parameters, have not been properly assessed.

In this study, we investigated the differences between dosimetric parameters from dose–volume histograms (DVHs) of the PTV and OARs in patients with prostate cancer: firstly at 6 MV and 18 MV linac photon energies; and secondly in 3D conventional versus conformal treatment plans.

MATERIALS AND METHODS

Patient selection and target definition

The computed tomography (CT) scans of twenty six patients who were treated with external beam radiation therapy for localized prostate cancer were obtained.

Corresponding author:
Dr. S.A. Vaezzadeh
Faculty of Medicine, Tehran University of Medical Sciences, Pour Sina Street, Keshavarz Blvd., Tehran, Iran.
Fax: *+98 21 88973653*
E-mail: *avaezzadeh@razi.tums.ac.ir*

The 3D treatment planning system (RTDosePLAN, Math Resolutions, Columbia, USA) was used to contour all of the structures and to compute the dose distribution for plans based on the convolution/ superposition algorithm. To create the planning target volume (PTV), 10 mm margin was added to the prostate plus seminal vesicles in all directions, except for the posterior where a 5 mm margin was added. OARs including bladder, rectum and femoral heads were delineated on the Planning CT images as full organs. However, the prescription dose was varied for each patient, 2 Gy per fraction was delivered.

Treatment plans

Considering all the beam arrangements used in the literature, eight conventional treatment plans were created (figure 1) and optimized for each patient using beam's eye view (BEV) technique at 6 MV energy to cover PTV by the 95% isodose as shown in table 1. The same plans were applied at 18 MV using Varian Clinac 2100C accelerator (Varian Inc., Connecticut, USA). Finally, based on the ICRU recommendation report No. 50 and 62 [17, 18], one 3D conformal treatment plan was obtained and compared with conventional treatment plan.

Comparison of different treatment plans

Analytical comparisons were performed among the plans. As noted earlier, these parameters were: the minimum, maximum and mean dose to volumes of interest (D_{min}, D_{max} and D_{mean}) for bladder, rectum and femoral heads, ID, CI and HI. Although, ID is the mean dose times the volume irradiated to any dose [11], following equation was used [14]:

$$ID = \sum D_i \times V_i \times \rho_i \qquad (1)$$

Where the D_i, V_i and ρ_i are dose, volume and density of a given voxel respectively. The CI, the ratio of the volume of total tissue receiving at least 95% (V95) of the

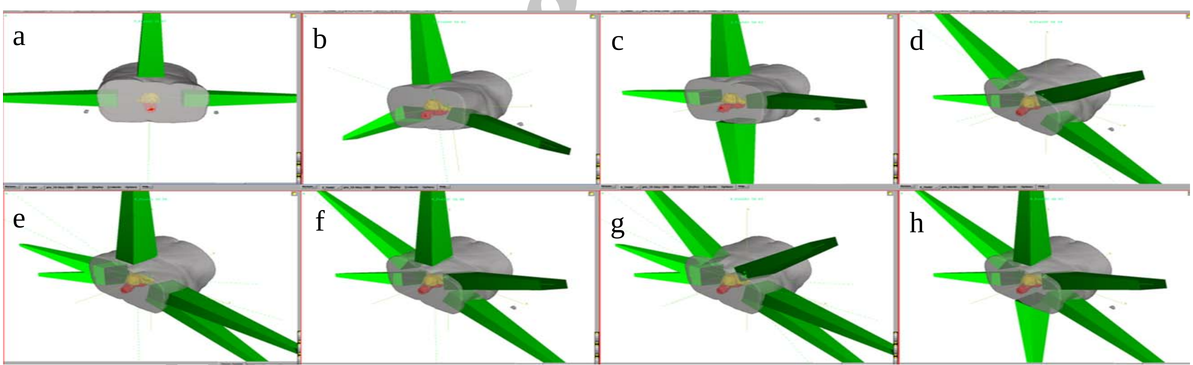

Figure 1. Beam arrangements of various treatment plans: a) 3F1, b) 3F2, c) 4F1, d) 4F2, e) 5F1, f) 5F2, g) 6F1, h) 6F2.

Table 1. Average gantry angle and beam's weight of various treatment plans.

plan		Gantry Angle (Average Weight from 200 cGy)					
		beam1	beam2	beam3	beam4	beam5	beam6
Three-fields	3F1	0(80)	90(60)	270(60)			
	3F2	0(100)	115(50)	245(50)			
Four-fields	4F1	0(80)	90(45)	180(30)	270(45)		
	4F2	50(55)	100(45)	260(45)	310(55)		
Five-fields	5F1	0(80)	90(45)	110(20)	250(20)	270(45)	
	5F2	0(70)	70(35)	110(25)	250(25)	290(35)	
Six-fields	6F1	50(30)	90(45)	110(25)	250(25)	270(45)	310(30)
	6F2	0(60)	70(35)	110(25)	180(20)	250(25)	290(35)

prescribed dose (V_{PTV}) to the volume of PTV was defined as [19-21]:

$$CI = \frac{V95}{V_{PTV}} \qquad (2)$$

And, HI was defined as the ratio of maximum dose to the prescribed dose for the PTV:

$$HI = \frac{D_{Max}}{D_{pres}} \qquad (3)$$

Anthropomorphic phantom

An anthropomorphic pelvic phantom has been designed and fabricated for imaging, treatment plans and dosimetry applications. Its configuration was based on CT slices obtained from a patient study. Individual slices were machined with corresponding contours of the Prostate, Bladder, Rectum and Pelvic bone. The phantom was made of Polymethyl - methacrylate (PMMA), while the pelvic bone and femurs were made of bone equivalent material, polytetrafluoroethylene (PTFE). Cylindrical grooves were machined in the phantom to allow placement of ionization chambers for dosimetry of prostate, bladder, rectum and femoral heads (figure 2). The phantom is being used to verify and evaluate the result of treatment plans.

Statistical analysis

Two-tailed paired t-test [1, 12, 14] was applied to compare the mean of the different measurements of the plans. A p-value of <0.05 was considered to be significant in the various comparisons.

RESULTS

The mean volumes of bladder, rectum, femoral heads and PTV were 204.3 (range 43-711) ml, 71.9 (range 28-173) ml, 150.6 (range 84-199) ml and 83.8 (range 44-193) ml, respectively. The mean age of patients was 57 years (range 44-63). All the plans were clinically equivalent in terms of PTV coverage.

Comparison between different conventional treatment plans

In table 2, the dose statistics for each OARs and PTV are listed for all 8 conventional treatment plans for 6 MV energy. The 4F2 and 6F1 plans, which use anterior oblique beams, appeared to deliver a lower mean dose to bladder (BD_{mean}=118.7±8.0 cGy, 120.1±7.9 cGy, respectively), while the 3F2 and 6F2 plans, with no lateral beams resulted in a lower mean dose to femoral heads (FD_{mean}=51.4±9.4 cGy, 63.4±8.2 cGy, respectively), compared with the other treatment plans. The 5F1 and 6F1 plans, which use posterior oblique beams instead of posterior beam, delivered a lower mean dose to rectum (RD_{mean}=90.0±8.6 cGy, 88.3±8.3 cGy, respectively) and better maxi-

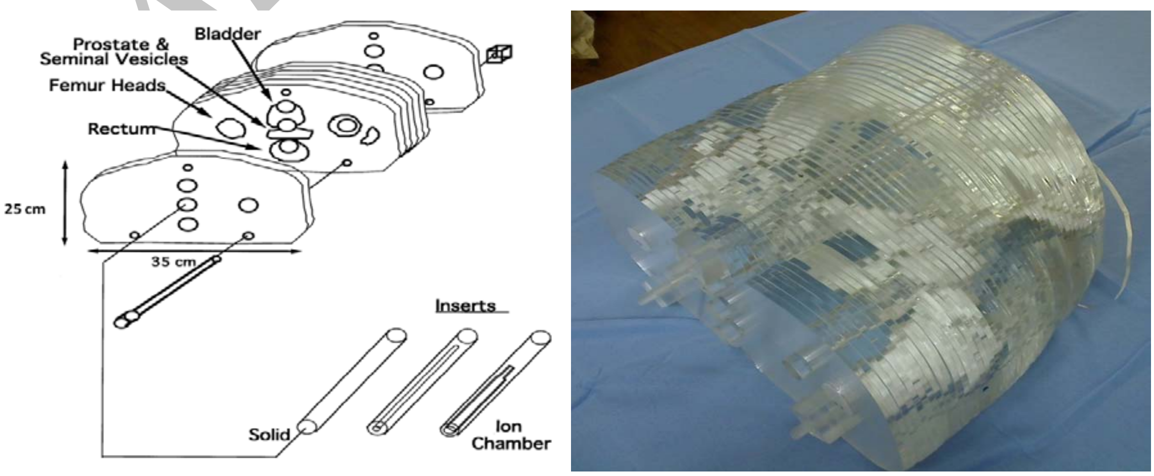

Figure 2. Heterogenic anthropomorphic pelvic phantom and its Inserts.

mum dose to the PTV (RD_{max}=208.3±0.6 cGy, 208.0±0.5 cGy, respectively) as well as a more uniform dose to the PTV, with HI of 1.04±0.01 for both of them. In contrast, the PTV homogeneities for the other techniques were relatively worse. Our observations showed that in the plans with more beams, conformity would be better and decreases from 4.53 for 3F1 to 4.11 for 6F2 gradually.

Comparison of 18 MV versus 6 MV treatment plans

Dosimetric parameters for the OARs and PTV at 18 MV energy are shown in table 3. By increasing the energy of beam to 18 MV, the 4F2 and 6F1 plans provided 28.9% and 39.7% reduction for RD_{min} compared to the other techniques (figure 1). Although, the mean dose to the femoral heads had 8.4% dose reduction with 18 MV relative to 6 MV for all plans consistently; as well as maximum dose of PTV; no generalities can be drawn regarding mean dose to the rectum with increasing the energy except 4F2 and 6F1 (tables 2 and 3).

Analyzing the results (tables 2 and 3) showed that on average, the CI and HI were improved 4% and 1% with increase in energy to 18 MV, respectively. The integral dose to normal tissues and uninvolved structures (table 4) was significantly decreased with increasing the energy and the number of applied beams.

Comparison of conformal versus conventional plans

For 13 patients 6F1 plan was chosen as a final plan respect to doses to OARs specially

Table 2. Mean ± standard deviation (in cGy) of dosimetric parameters for OARs and PTV in different plans at 6 MV energy.

6MV		3F1	3F2	4F1	4F2	5F1	5F2	6F1	6F2
Bladder	BD_{min}	42.2±23.2	45.6±20.2	48.7±21.4	15.6±5.8	34.1±15.8	37.1±19.8	16.8±7.5	37.3±17.2
	BD_{max}	214.3±1.6	207.1±1.4	207.5±0.6	207.2±1.3	205.6±0.5	210.5±1.1	205.8±0.6	208.9±1.3
	BD_{mean}	138.7±8.2	145.6±9.0	142.2±8.5	118.7±8.0	134.1±8.1	131.4±7.8	120.1±7.9	132.6±8.1
Rectum	RD_{min}	43.3±6.3	44.4±6.7	47.3±8.5	23.9±4.2	32.8±4.9	31.7±4.9	26.7±5.5	34.5±5.8
	RD_{max}	197.0±2.6	203.6±2.8	198.4±1.6	201.7±2.3	200.3±2.3	198.0±1.8	200.5±2.6	199.7±2.4
	RD_{mean}	102.9±10.7	106.0±9.9	98.1±9.3	101.0±9.4	90.0±8.6	97.8±8.8	88.3±8.3	101.6±9.8
Femoral heads	FD_{min}	26.4±11.9	10.1±2.9	21.7±11.1	11.9±3.3	25.4±9.6	14.6±3.4	27.7±9.2	12.8±6.4
	FD_{max}	154.5±7.6	120.7±10.0	135.1±4.4	158.9±17.4	145.3±6.2	149.9±10.5	163.6±13.1	130.8±8.9
	FD_{mean}	115.8±10.0	51.4±9.4	101.2±8.3	66.5±11.1	130.8±20.2	73.2±10.1	109.1±8.6	63.4±8.2
PTV	PD_{max}	216.1±1.4	209.8±0.8	209.0±0.5	210.7±1.0	208.3±0.6	213.2±1.1	208.0±0.5	211.5±1.0
	CI	4.53±1.01	4.53±1.11	4.66±0.99	4.62±1.09	4.17±0.89	4.26±0.93	4.27±0.97	4.11±0.89
	HI	1.08±0.03	1.04±0.02	1.04±0.01	1.05±0.02	1.04±0.01	1.07±0.02	1.04±0.01	1.06±0.02

Table 3. Mean ± standard deviation (in cGy) of dosimetric parameters for OARs and PTV in different plans at 18 MV energy.

18MV		3F1	3F2	4F1	4F2	5F1	5F2	6F1	6F2
Bladder	BD_{min}	32.5±18.7†	36.8±18.9†	42.5±21.0†	8.4±4.0†	32.6±17.7	27.3±14.2	11.9±7.6†	32.7±17.3†
	BD_{max}	212.3±1.9	205.6±1.0†	206.5±1.1	205.3±0.8†	204.6±0.4†	207.9±0.9†	204.6±0.4†	206.4±0.8†
	BD_{mean}	134.3±8.6†	141.0±9.2†	137.9±8.8†	113.8±8.2†	130.3±8.4†	127.3±8.0†	116.7±8.3†	130.6±7.8
Rectum	RD_{min}	41.3±9.2	37.5±7.2†	40.9±8.7†	17.0±4.3†	27.8±5.1†	24.9±5.1†	16.1±2.9†	30.9±6.5
	RD_{max}	199.8±3.2	201.9±1.6†	198.7±1.4	201.4±1.9	199.2±2.8†	199.2±1.2†	200.5±1.6	200.0±1.3
	RD_{mean}	104.1±11.1	104.9±9.6†	96.5±9.4†	99.3±9.0	88.5±8.3†	97.8±8.7	87.3±8.2†	101.9±9.9
Femoral heads	FD_{min}	22.1±11.6	6.3±2.1†	17.6±11.1†	14.4±18.9†	21.8±9.0†	10.0±3.5†	22.6±8.6†	9.8±5.9†
	FD_{max}	133.6±7.8†	109.5±9.0†	115.1±3.4†	151.1±19.9†	135.3±6.1†	142.5±12.4†	158.5±14.4†	123.8±8.8†
	FD_{mean}	106.8±10.1†	45.7±9.1†	91.6±7.7†	59.2±11.2†	130.8±20.2†	65.9±8.6†	99.9±8.8†	57.4±7.6†
PTV	PD_{max}	214.6±2.0	208.3±0.6†	207.3±0.4†	208.5±0.8†	206.6±0.4†	210.5±0.8†	206.7±0.4†	208.9±0.9†
	CI	4.33±1.25	4.31±1.05†	4.52±0.46†	4.46±1.06†	3.95±0.90†	4.06±0.82†	4.07±1.07†	4.00±0.85†
	HI	1.07±0.04	1.04±0.01†	1.04±0.01†	1.04±0.02†	1.03±0.01†	1.05±0.02†	1.03±0.01†	1.04±0.02†

†, indicating the p-value < 0.05 in comparison with 6 MV energy

rectum and for other 5F1 was applied. Conformal plan using multi leaf collimator (MLC) was created for each patient. In comparison with conventional plans, conformal planning reduced minimum dose to bladder, rectum and femoral heads by 57.3%, 44.4% and 55.6%, respectively. In addition, the mean dose to OARs decreased by 32.4%, 16.9% and 20.2%, respectively. For the HI, the difference due to 3D-CRT was significant but small, while the CI and ID were significantly improved by 44.6% and 30.8%, respectively.

Experimental measurements

In order to assess the value of planning results, the measurements were performed for a 5F1 treatment plan using Farmer ionization chamber (PTW, Freiburg, Germany) at desired points in the anthropomorphic pelvic phantom. Relative differences between calculated and measured doses were 1.4%, 0.0%, 3.0% and 5.0% for prostate, bladder, rectum and femoral heads, respectively.

DISCUSSION

In this study, we compared the dosimetric parameters of different treatment plans. With careful planning in regard to choice of beam angles, beam weighting, and recognition of potential exposure of normal tissues to exit dose, our study showed that with an accurate beam arrangement, even with low energy beams, we were able to improve target dose conformity, critical tissue sparing, and reduction of integral dose. Based on our result, 6F1 provided lower dose to the rectum and bladder because of two set of oblique fields that put them out of radiation fields. Although, high dose to femoral heads due to two lateral fields is still a problem, low lateral beam's weight would be eliminated. In agreement with observations published by Aoyama *et al.* [11] our result showed that high energy beam plans resulted in lower normal tissue integral dose than low energy plans. On the other hand, Mackie *et al.* [15] showed that the integral dose for high energy beams is almost equal to low energy beams, because the reduction due to entrance buildup was nearly offset by the higher exit dose and the need for a larger field boundary margins for high-energy beams. In contrast with our result they showed that the integral dose does not depend on the number of beams used. We have demonstrated that by increasing the number of beams the rate of reduction of ID due to high energy used was decreased.

Ashman *et al.* [1] concluded that in Comparison with conventional 2D planning, conformal planning for whole pelvic radiotherapy resulted in significant reductions in the doses delivered to the rectum and bladder in agreement with our results that shows 3D conformal treatment planning provided great reduction of dose to OARs and normal tissues in addition to the improvements in CI and ID.

In conclusion, the 6F1 treatment plan in comparison to other plans offers minimum dose to critical organs and sufficient dose to prostate. Increasing the photon energy, improves the dosimetric parameters of bladder, femoral heads and PTV, but no statistically significant differences for radiation dose to the rectum were observed. By increasing the number of beams, one can compensate the low energy defect. Compared with conventional treatment

Table 4. Mean ± standard deviation (in Gy.Kg) of integral dose in different plans at two energies.

ID	3F1	3F2	4F1	4F2	5F1	5F2	6F1	6F2
6 MV	6.10±1.29	5.68±1.21	5.63±1.16	5.98±1.11	5.80±1.09	6.01±1.08	5.97±0.96	5.58±1.03
18 MV	5.34±1.20†	4.92±1.05†	4.87±1.01†	5.17±0.97†	5.05±0.90†	5.23±0.99†	5.19±0.87†	4.95±0.99†

†, indicating the p-value < 0.05 in comparison with 6 MV energy

techniques, 3D-CRT offered the most conformity in the delivery of tumoricidal doses to the prostate while sparing dose to critical, uninvolved structures with lower integral dose. With increasing interest in inverse planning and IMRT techniques and requirement to have the number of beams, it's recommended to apply 5 or 6 field plans as the first choice.

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REFERENCES

1. Ashman JB, Zelefsky MJ, Hunt MS, Leibel SA, Fuks Z (2005) Whole pelvic radiotherapy for prostate cancer using 3D conformal and intensity-modulated radiotherapy. *Int J Radiat Oncol, **63**:765-71*.
2. Breen SL, Kehagioglou P, Usher C, Plowman PN (2004) A comparison of conventional, conformal and intensity-modulated coplanar radiotherapy plans for posterior fossa treatment. *Br J Radiol, **77:** 768-74.*
3. Mock U, Georg D, Bogner J, Auberger T, Potter R (2004) Treatment planning comparison of conventional, 3D conformal, and intensity-modulated photon (IMRT) and proton therapy for paranasal sinus carcinoma. *Int J Radiat Oncol Biol Phys, **58:** 147-54*.
4. Nutting CM, Rowbottom CG, Cosgrove VP, Henk JM, Dearnaley DP, Robinson MH, *et al.* (2001) Optimisation of radiotherapy for carcinoma of the parotid gland: a comparison of conventional, three-dimensional conformal, and intensity-modulated techniques. *Radiother Oncol, **60:** 163-72*.
5. Oh CE, Antes K, Darby M, Song S, Starkschall G (1999) Comparison of 2D conventional, 3D conformal, and intensity-modulated treatment planning techniques for patients with prostate cancer with regard to target-dose homogeneity and dose to critical, uninvolved structures. *Med Dosim, **24:** 255-63*.
6. Sale CA, Yeoh EE, Scutter S, Bezak E (2005) 2D versus 3D radiation therapy for prostate carcinoma: a direct comparison of dose volume parameters. *Acta Oncol, **44**: 348-54*.
7. Adams EJ, Warrington AP (2008). A comparison between cobalt and linear accelerator-based treatment plans for conformal and intensity-modulated radiotherapy. *Br J Radiol, **81:** 304-10*.
8. Ding M, Newman F, Kavanagh BD, Stuhr K, Johnson TK, Gaspar LE (2006) Comparative dosimetric study of three-dimensional conformal, dynamic conformal arc, and intensity-modulated radiotherapy for brain tumor treatment using novalis system. *Int J Radiat Oncol, **66:** S82-S6*.
9. Jereczek-Fossa BA, Cattani F, D'Onofrio A, Cambria R, Kowalczyk A, Corallo A, *et al.* (2006) Dose distribution in 3-dimensional conformal radiotherapy for prostate cancer: Comparison of two treatment techniques (six coplanar fields and two dynamic arcs). *Radiotherapy and Oncology, **81:** 294-302*.
10. Reddy N, Mazur A, Osian A, Sampath S, Hadley C, Poli J, *et al.* (2003) DVH for rectum and bladder in 3D conformal treatment of prostate: Volume dependence of x-ray dose. *Medical Physics, **30:** 1505*.
11. Aoyama H, Westerly DC, Mackie TR, Olivera GH, Bentzen SM, Patel RR, *et al.* (2006) Integral radiation dose to normal structures with conformal external beam radiation. *Int J Radiat Oncol, **64:** 962-7*.
12. Weiss E, Siebers JV, Keall PJ (2007) An analysis of 6-MV versus 18-MV photon energy plans for intensity-modulated radiation therapy (IMRT) of lung cancer. *Radiotherapy and Oncology, **82:** 55-62*.
13. Grzadziel A, Grosu AL, Kneschaurek P (2006) Three-dimensional conformal versus intensity-modulated radiotherapy dose planning in stereotactic radiotherapy: application of standard quality parameters for plan evaluation. *Int J Radiat Oncol, **66:** S87-S94*.
14. Hermanto U, Frija EK, Lii MFJ, Chang EL, Mahajan A, Woo SY (2007) Intensity-modulated radiotherapy (IMRT) and conventional three-dimensional conformal radiotherapy for high-grade gliomas: Does IMRT increase the integral dose to normal brain? *Int J Radiat Oncol, **67:** 1135-44*.
15. Mackie T, Kissick M, Jeraj R, Tome W, Fenwick J, Olivera G, *et al.* (2004) Integral dose in external beam photon radiotherapy. *Medical Physics. **31:** 1721*.
16. Wu VW, Kwong DL, Sham JS (2004) Target dose conformity in 3-dimensional conformal radiotherapy and intensity modulated radiotherapy. *Radiother Oncol, **71:** 201-6*.
17. International Commission on Radiation Units and Measurements Report 50, Prescribing, Recording and Reporting Photon Beam Therapy Bethesda, Maryland, USA 1993.
18. International Commission on Radiation Units and Measurements Report 62, Prescribing, Recording and Reporting Photon Beam Therapy (Supplement to ICRU Report 50). Bethesda, Maryland, USA 1999. Report No.: 62.
19. Nedzi LA, Kooy HM, Alexander E, 3rd, Svensson GK, Loeffler JS (1993) Dynamic field shaping for stereotactic radiosurgery: a modeling study. *Int J Radiat Oncol Biol Phys, **25:** 859-69*.
20. Shaw E, Kline R, Gillin M, Souhami L, Hirschfeld A, Dinapoli R, *et al.* (1993) Radiation-Therapy Oncology Group - Radiosurgery Quality Assurance Guidelines. *Int J Radiat Oncol, **27:** 1231-9*.
21. Shaw E, Scott C, Souhami L, Dinapoli R, Kline R, Loeffler J, *et al.* (2000) Single dose radiosurgical treatment of recurrent previously irradiated primary brain tumors and brain metastases: Final report of RTOG protocol 90-05. *Int J Radiat Oncol, **47:** 291-8.*