IMRT treatment plans in prostate carcinoma: Comparison with 3DCRT. Dosimetric study

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Abstract

Introduction: The concave dose distributions produced by intensity modulated radiotherapy (IMRT) of prostate cancer increases the scope for dose escalation as the high dose region wraps around the overlapping rectum in the PTV (planning target volume) so conforms the dose to the target volume with better rectum sparing.
Aim: The aim of this study was to compare IMRT with 3DCRT plans for low risk prostate cancer patients and to evaluate to what extent IMRT plans can achieve target conformity and sparing for rectum, bladder and femoral heads compared with 3DCRT plans.
Methods: CT studies of ten low risk prostate cancer patients were planned using 3DCRT and IMRT plans. PTV2, PTV1, rectum, bladder and femoral heads were outlined. 78 Gy was prescribed to the isocenter. Dose volume histogram parameters (DVPs) for both plans were compared and analyzed statistically.
Results: PTV2 dose coverage was significantly superior in IMRT plans but its dose homogeneity was significantly superior in 3DCRT. On the other hand, PTV1 dose coverage and homogeneity in IMRT plans were not significantly different from the 3DCRT plans. This was with greater sparing of the rectum, bladder and femoral heads with IMRT plans.
Conclusion: Although IMRT plans usually give comparable PTV1 dose coverage to the 3DCRT plans, the PTV2 coverage is significantly superior. This is with greater sparing of the rectum, bladder and femoral heads in IMRT plans which gives the scope to escalate the dose to more than 78Gy.

I declare that there is no conflict of interest with any financial organization regarding the material in this manuscript

Introduction

Although 3DCRT delivers homogeneous dose to the target volume, it cannot handle the concavity of the PTV around the rectum. This makes dose escalation to the tumor while sparing the rectum very difficult.[1]
The concave dose distributions produced by IMRT plans present a significant advantage over 3DCRT. The high dose region wraps around the overlapping rectum in the PTV and thus conforms the dose to the target volume and achieves a higher level of rectum sparing. This increases the scope for dose escalation. However this is commonly associated with areas of under-dosage in the target volume [2]

The accurate outlining of the target volumes, margins, rectum and bladder is crucial in prostate IMRT. Reduction in the margin without immobilisation of the patient may lead to under-dosing of the target volume [3].

Prostate motion could cause more than 5mm shift in the anterior direction. This can affect the target coverage and expose a greater volume of rectum to high doses resulting in high incidence of rectal bleeding. Problems relating to unacceptable dose to the rectum limit escalation of the prostate dose more than problems affecting the bladder [4-6]

The probability of tumour control and normal tissue complications after radiation therapy are dose dependent. The tolerance dose of critical structures is also dependent on the volume of irradiated normal tissues within the PTV. [5,7,8]

Methods

CT studies of ten randomly selected patients with low risk prostate cancer from future hand oncology centre (age ranges 51-78, mean 69 years) planned and calculated with 15 MV photon beam on CMS treatment planning system (Xio, Germany) using the data for the 15MV photon beam of Primus linear accelerator (Siemens, Germany). The CT scan slices were spaced 5mm from the sacroiliac joint to the lesser trochanter. All patients scanned in a supine position with a comfortably full bladder.

Various volumes of interest were defined: CTV (prostate and seminal vesicle), PTV2 (prostate+1.0cm margin) and PTV1 (CTV+1.0cm margin) were outlined.

Organs at risk (OAR) including rectum, bladder and femoral heads were outlined. Bladder and rectum were defined by contouring the whole organ including the contents.

The average of the volume of bladder, rectum, PTV1 & PTV2 was calculated (range, 77cc-294cc, mean, 160cc), (range, 21cc-123cc, mean, 63cc), (range, 66cc-655.5cc, mean, 237cc) and (range, 48cc-414cc, mean, 147cc) respectively.

3DCRT and inverse planned IMRT plans were planned. 3DCRT carried out in 2 phases. In phase 1 & Phase 2, 5 fields at gantry angle 0^0, 57^0, 90^0, 270^0 & 296^0 were used to irradiate PTV1 & PTV2 respectively. In phase 1, the beams were adjusted to conform to PTV1 using MLCs and in phase 2, the MLCs were modified to conform the beams to PTV2 and to shield the rectum.

A total dose of 78Gy was prescribed to the isocentre following the ICRU definition for normalisation point[9]. In the first phase of 3DCRT treatment, a dose of 54Gy was delivered to PTV1. In the second phase of the treatment an additional dose of 24Gy was delivered to PTV2.

Inverse planned IMRT was carried out using step-and-shoot technique with 7 non-opposing fields at gantry angle 0^o, 50^o, 108^0, 153^o, 204^0, 255^0 & 305^o with 10 intensity levels and 50-87 segments.

The tolerance doses for rectum and bladder were; for the rectum the aim was to keep the dose to 66%, 50%, 25% and 10% of the volume ($D_{66\%}$, $D_{50\%}$, $D_{25\%}$ and $D_{10\%}$) to be less than 45Gy, 55Gy, 65Gy and 70Gy respectively. Regarding the dose to the bladder, the aim was to keep the dose to 50%, 33% and 20% of the bladder volume ($D_{50\%}$, $D_{33\%}$, and $D_{20\%}$) to be less than 60Gy, 60-65Gy and 65Gy respectively[10,11]. The treatment also aimed to keep the rectal volume receiving 50Gy & 70Gy (V_{50Gy} & V_{70Gy}) below 60-65% and 25-30% respectively [12]. For both plans, the rectum volume receiving 25Gy, 55Gy, 60Gy, 65Gy, 75Gy and 80Gy (V_{25Gy}, V_{55Gy} V_{60Gy} $V_{65Gy,}$ V_{75Gy} and V_{80Gy}) and bladder volume receiving 50Gy, 60Gy, 65Gy & 70Gy, 75Gy and 80Gy (V_{50Gy}, V_{60Gy} V_{65Gy} $V_{70Gy,}$ V_{75Gy} and V_{80Gy}) were compared. The tolerance of femoral head was taken to be less than 45Gy maximum point dose.

To optimize the IMRT plan, the dose constraint was 78Gy for PTV2 and 54Gy for PTV1. For rectum; the dose of 60Gy & 35Gy was specified to 17% & 35% of the rectum volume and no volume should receive more than 66Gy. For bladder, the dose of 45Gy & 34Gy was specified to 25% & 50% of its volume and no volume should receive more than 60Gy. For femoral heads, 30Gy was specified to 9% of the volume and no volume should receive more than 35Gy.

Both plans were compared for PTV1 & PTV2 dose coverage & homogeneity, sparing of rectum, bladder and femoral heads and the maximum body dose. To assess the differences in PTV1 & PTV2 dose coverage, dose distribution and DVPs (the minimum dose, dose to 95% of the volume ($D_{95\%}$) and the maximum point dose of the PTV1 & PTV2) were used. Dose homogeneity within PTV1 & PTV2 was calculated as max dose /min dose. To evaluate the differences in the sparing of the rectum, bladder and femoral heads between the two techniques, their DVPs were used.

This study had approval of Institutional Review Board as a retrospective one in which confidentially of records was considered.

Statistical analysis

The DVPs for both plans were statistically analysed for any significant difference in dose coverage and homogeneity within PTV1 & PTV2. Rectum, bladder and femoral head DVPs, and body max dose were also compared using Wilcoxon Signed-Ranks test of SPSS (version 18). A P value of less than 0.05 was taken as statistically significant.

Results

3DCRT and inverse planned IMRT plans produced for 78Gy were compared for ten patients (Tables 1-3).

Table 1 gives the statistical analysis for PTV2 & PTV1 DVPs comparing 3DCRT and IMRT plans. It shows that the PTV1 coverage (PTV1 $D_{95\%}$) was not significantly different in both plans (p=0.678) with the maximum dose significantly higher with CR plans (p=0.007). On the other hand, the PTV2 coverage (PTV2 $D_{95\%}$) and the PTV2 maximum doses were significantly higher with IMRT plans (p=0.028 & 0.005). It also shows that the average minimum dose of PTV1 & PTV2 for both plans was comparable (p=0.386 &0.386).

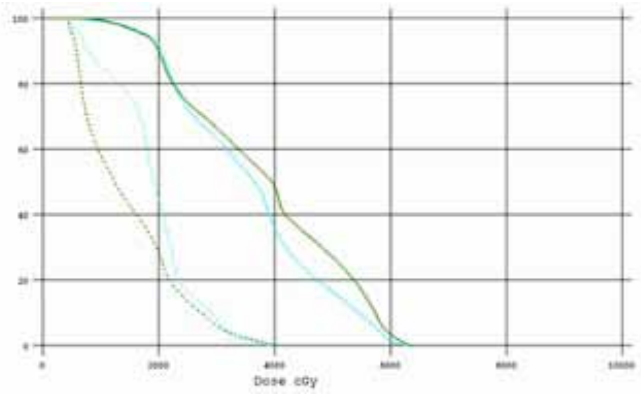
The dose homogeneity within PTV1 was comparable in both plans (average, 1.45 for CR compared to 1.58 for IMRT, p=0.093) while within PTV2, it was significantly better for CR (average 1.07 compared to 1.14 for IMRT plans, p=0.005).

Table 2 & 3 gives the statistical analysis for rectum, bladder and femoral heads DVPs comparing 3DCRT and IMRT plans (figure 1). Table 2 shows that there is a significant reduction of the most of rectum DVPs with IMRT plans (However this reduction was not significantly different in both plans for $D_{66\%}$, $D_{50\%}$, $D_{10\%}$, V_{25Gy} &V_{50Gy}). This reduction increased in the range of 50Gy to 75Gy. So IMRT achieves better rectum sparing.

Table 2 shows that there is a significant reduction (31% & 33%) of the average of the maximum point dose of right and left femoral heads, with IMRT plans compared with 3DCRT (P=0.005)

Table 3 also shows that there is a reduction of bladder DVPs with IMRT plans except for $BD_{50\%}$, which was higher with IMRT and BV_{50Gy} which was comparable in both plans. This reduction increased in the range of 50Gy-80Gy and IMRT achieves better sparing of the bladder. However this reduction was not significantly different for both plans.

Body maximum dose, IMRT plans shows a significant reduction (11%) compared to 3DCRT (average 70 Gy compared to 79 Gy for 3DCRT) (p=0.005).



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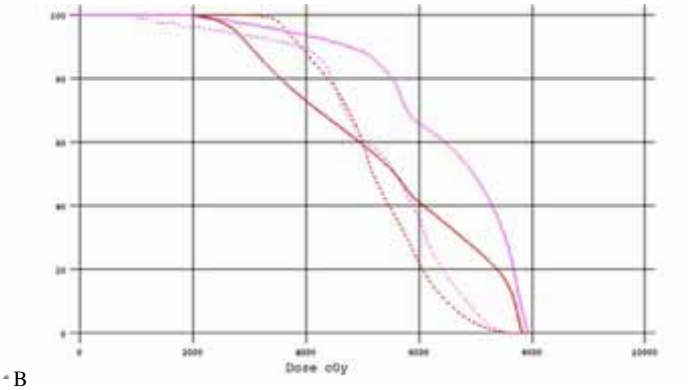

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Fig 1: Dose volume histogram comparison for 3DCRT and IMRT plan for (A) rectum in green and bladder in blue and for (B) right and left femoral heads. (IMRT plan is the dashed curve)

Table 1: DVPs for PTV2 & PTV1 comparing 3DCRT (CR) and IMRT plans (IM). The dose prescribed is 78Gy.

DVPs	Minimum	Maximum	Mean	P values
PTV2				
PTV2 min (IM)	70	76.5	73	0.386
PTV2 min (CR)	71.5	75	74	
PTV2 max (IM)	81	86	84	0.005
PTV2 max (CR)	77	82.6	79	
PTV2 $D_{95\%}$ (IM)	75.4	78.7	76.7	0.028
PTV2 $D_{95\%}$ (CR)	74.55	76.5	76	
PTV1				
PTV1 min (IM)	44	68	54	0.386
PTV1 min (CR)	51	70	55	
PTV1 max (IM)	44	69	54	0.007
PTV1 max (CR)	77	83	79	
PTV1 $D_{95\%}$ (IM)	50	77	60	0.678
PTV1 $D_{95\%}$ (CR)	52	75	60	

Table 2: DVPs for rectum and head of femurs comparing 3DCRT (CR) and IMRT plans (IM).

DVPS	Minimum	Maximum	Mean	Reduction% P values
Rectum				
R D66% (IM)	2	51	36	-7% 0.575
R D66% (CR)	10	60	39	
R D50% (IM)	3	56	41	-14% 0.093
R D50% (CR)	28	70	48	
R D25% (IM)	26	64	53	-16% 0.013
R D25% (CR)	49	76	63	
R D10% (IM)	53	75	65	-7% 0.059
R D10% (CR)	58	78	70	
R V25Gy (IM)	25	100	78	-9% 0.169
R V25Gy (CR)	54	100	86	
R V50Gy (IM)	11	72	39	-25% 0.059
R V50Gy (CR)	24	95	52	
R V55Gy (IM)	8.5	52	28	-41% 0.022
R V55Gy (CR)	19	85	48	
R V60Gy (IM)	6	36	20	-36% 0.028
R V60Gy (CR)	10	66	31	
R V65Gy (IM)	3	24	12.5	-54% 0.005
R V65Gy (CR)	6	59	27	
R V70Gy (IM)	0.7	16	7	-65% 0.005
R V70Gy (CR)	4	49	20	
R V75Gy (IM)	0	10	3	-75% 0.008
R V75Gy (CR)	0	31	12	
Head of femurs				
Max dose (IM) (Rt)	42	46	44	-31% 0.005
Max dose (CR) (Rt)	56	79	64	
Max dose (IM) (Lt)	38	48	42	-33% 0.005
Max dose (CR) (Lt)	53	78	63	

Table 3. DVPs for bladder comparing 3DCRT (CR) and IMRT plans (IM).

DVPS	Minimum	Maximum	Mean	Reduction% P values
Bladder				
B D50% (IM)	2	54	37.5	15% 0.314
B D50% (CR)	7	56	32	
B D 33% (IM)	4	61	45	-10% 0.110
B D33% (CR)	19	78	50	
B D20% (IM)	8	69	55	-11% 0.051
B D20% (CR)	34	80	62	
B V50Gy (IM)	9	67	40	0 0.515
B V50Gy (CR)	13	74	40	
B V60Gy (IM)	8	35	20	-26% 0.111
B V60Gy (CR)	9	64	27	
B V65Gy (IM)	7	26	14	-39% 0.110
B V65Gy (CR)	8	58	23	
B V70 Gy (IM)	3	18	9	-50% 0.11
B V70Gy (CR)	6	51	18	
B V75 Gy (IM)	0.3	11	5	-55% 0.214
B V75Gy (CR)	2	42	11	
B V80 Gy (IM)	0	5	1	-66% 0.715
B V80Gy (CR)	0	24	3	

Discussion

The concave dose distributions for prostate cancer produced by IMRT plans present a significant advantage over 3DCRT. This was achieved, discussed and compared to the works done by other authors.

The results of the current work were compared to the Bauman et-al[13] and Vaarakamp et al[14] works. Bauman et al[13] compared a simplified intensity modulated arc therapy (SIMAT) with 3DCRT. They achieved lower PTV2 maximum and mean dose with similar $D_{95\%}$ in SIMAT plans compared to 3DCRT. Rectum sparing was achieved particularly in the lower dose region. Vaarakamp et al[14] compared 5-field inverse planned IMRT, multisegment forward planned IMRT (MSRT) and 3DCRT, they achieved lower PTV1 & PTV2 coverage in inverse planned IMRT compared to the other two techniques. All OARs DVPs were lower for IMRT compared with 3DCRT but they were not significantly different from MSRT. On the other hand, in the current work, although IMRT dose coverage and homogeneity within PTV1 was comparable to the 3DCRT plans, the PTV2 coverage was significantly superior in IMRT plans. This was with greater sparing of the rectum, bladder and femoral heads in IMRT plans which give the scope to escalate the dose to more than 78Gy.

Jeff Michalski[15] also compared 3DCRT with IMRT; in his study IMRT was associated with a statistically significant reduction in high dose volume of the rectum and bladder doses: the percent of the bladder volume receiving 65 Gy, 70 Gy and 75 Gy were 25.3%, 22.2%, and 17.7% for 3DCRT compared with 19.7%, 16.6% and 13.1% for IMRT. The median rectum V_{65Gy}, V_{70Gy} & V_{75Gy} were 27.4%, 21.7%, & 15.8% for 3DCRT and 23.0%, 18.2% & 13.0% for IMRT. In the current study, these values were far lower than those achieved with Jeff so the sparing of rectum and bladder was superior in IMRT plans compared with our 3DCRT plans and also compared with jeff results (table 2). Jeff also concluded that IMRT is associated with a statistically significant reduction in acute and late grade 2 and GI toxicity so IMRT can be used for dose escalation while decreasing acute and late toxicity.

Helal et al [16,17] compared 3DCRT plans (4 fields in 2 phases) and step-and-shoot inverse planned IMRT (5 non-opposing fields). The dose prescribed to the isocenter for all plans was 74 Gy. In their study PTV1 coverage was significantly improved in IMRT plans. Although the PTV2 coverage was better in 3DCRT plans, the minimum $D_{90\%}$ was 67 Gy and the average $D_{90\%}$ was 72 Gy in IMRT plan. Rectum $D_{66\%}$, & $D_{50\%}$, bladder $D_{50\%}$ and $D_{33\%}$ and bladder and rectum V_{50Gy} & V_{70Gy} were significantly lower in IMRT plans (Rectum $D_{25\%}$ and bladder $D_{20\%}$ were comparable in both plans). As the DVPs for the rectum and bladder were significantly lower than their pre-specified tolerance level so dose was escalated to 78 Gy.

Conclusion

IMRT plans usually give comparable PTV1 dose coverage to the 3DCRT plans. The PTV2 coverage is significantly superior in IMRT plans. This is with greater sparing of the rectum, bladder and femoral heads in IMRT plans which gives the scope to escalate the dose to more than 78Gy.

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