Clinical Application of the Dual Energy Photon Beam Using 6 MV and 10 MV X-ray

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Some modern accerelators provide a dual energy for photon beam treatment. The main advantages of dual energy in the treatment of rectosigmoid or rectal cancer are as follows.

1. Dose in the critical organ such as small intestine, bladder and genital organ are reduced.

2. Presacral and perineal area is fully covered.

Dose distribution analysis such as calculation of dose in a target volume, isocenter, D_{max} and dose spectrum in any region of interest are possible.

Examples of plan are given and results are discussed.

Key Words: Dual photon accelerator, Rectal carcinoma, Treatment planning

INTRODUCTION

Irradiation is being used alone or in combination with surgery with increasing frequency in the treatment of colorectal malignancies. A significant portion of patients with the more advanced colorectal carcinoma suffer from the complication of recurrence, metastases and death if treated by surgery alone[1~3].

Any therapeutic gains achieved with XRT might be offset by an unnecessary increase in complications unless close cooperation exists between physicians concerned in selecting patient groups which have definitive indication for the addition of XRT and in optimizing radiation dose delivery.

For the group of patients with technically resectable lesions who are at high risk for local recurrence pre or postop dose level required to markedly decrease the local failure incidence is 4500~5000 rad/5~6 wks[1,4]. At this dose level, the incidence of small bowel damage is minimal[5]. Adhesion can occur and techniques should be used to minimize the volume of small intestine and other normal tissure within irrdiated portals to achive high dose levels safely is dependent on close interaction between the surgeon and radiation oncologist in defining noraml and tumor tissue and displacing the normal tissue from the tumor volume whenever possible.

In an effort to minimize both acute toxicity and chronic complications of abdomonal and pelvic RT positional shifts of small intestine are more likely to occur with patients prone rather than supine. Several methods have been reported to reduce small bowel dose such as bladder distension, operative reconstruction of small bowel or multiple field technique, or shringking field technique[6,7].

The intent of this paper is to demonstrate advantages of dual energy photon beam X-ray in sparing small intestine and decreasing potential bladder and genital organ complication in patient with rectosigmoid or rectal malignancies.

Technical aspects of treatment planning will be presented. Advantage of dual photon will be illustrated by comparng isodose contours of 3 field technique to those of 6 MV or 10 MV single photon in representative patients.

MATERIAL AND METHOD

Total 15 patient with rectosigmoid or rectal cancer were treated with combined 6 MV and 10 MV X-rays using dual photon linear accelerator. 3 patient were treated for postoperative recurrent disease, 2 were treated for inoperable disease and 10 received radiation for postoperative adjuvant therapy. 9 patients were female and 6 were male. Total 7 patient underwent APR operation, 5 patient had anterior resection, 1 had total colectomy and protectomy and 2 had colostomy only.

Age distirbution were 28 to 73 with median age of 54.

Astler-Coller stage B2 were 2, C1 was 1, C2 were 9 and unspecified patient were 3.

All patient were simulated on prone position. 3 field technique with 2 lateral wedge pair and one anterior field were applied. 6 MV photon beam for vertex field and 10 MV for 2 lateral beam were used. For those undergoing a low anterior resection, the inferior field was at the bottom of the obturator foramina or 3~5 cm below the anastomosis. For those undergoing an APR, entire perineum was included in all field. Shaped lateral fields were used to spare soft tissues and muscle posteriorly. Anterioly, the field was not routinely designed to include external ilac lymph nodes. Bowel located anteriorly and a portion of the bladder were spared in the lateral field.

For comparison of this technique with single energy beam, 3 field technique with 6 MV or 10 MV photon beams were used. Maximum, minimaum and mean dose in the region of interst were calculated using Mevaplan treatment planning computer.

RESULT

A set of three beams (AP and a pair of 45 or 60 degree wedge pair lateral beams) on pelvis target was applied. Fig. 1 shows the field configuration, target volume, trasverse contour through the central axis, and the point used to define the selected normal tissue and tumor structure lying within the treatment volume.

P1 is isocenter which is the normalization point.

ROI A is field inside of bladder contour below the edge of lateral treatment field.

ROI B is contour of right femoral head (part of region is lateral and inferior of beam).

Wedge is designed to provide a large dose gradient across the treatment field. Weighting factors are defined as contributions of beams to a reference point. Determination of weighting factors for the beams to achieve a desirable distribution is a complex procedure which may involve judgement by physist and clinician. Time weighting method was applied. Weighting of 1 from vertex field, and 0.5 from each lateral field or equal weighting of three field was done.

Dose at tumor volume are determined by the contribution of all three field and should be at least 95% for 100% normalization to the isocenter

P2 is at the depth dose maximum which depends on beam energy and wedge angle.

The dose of ROI A is determined mainly by the contribution of the vertex field.

Fig. 2 shows advantage of dual enrgy photon

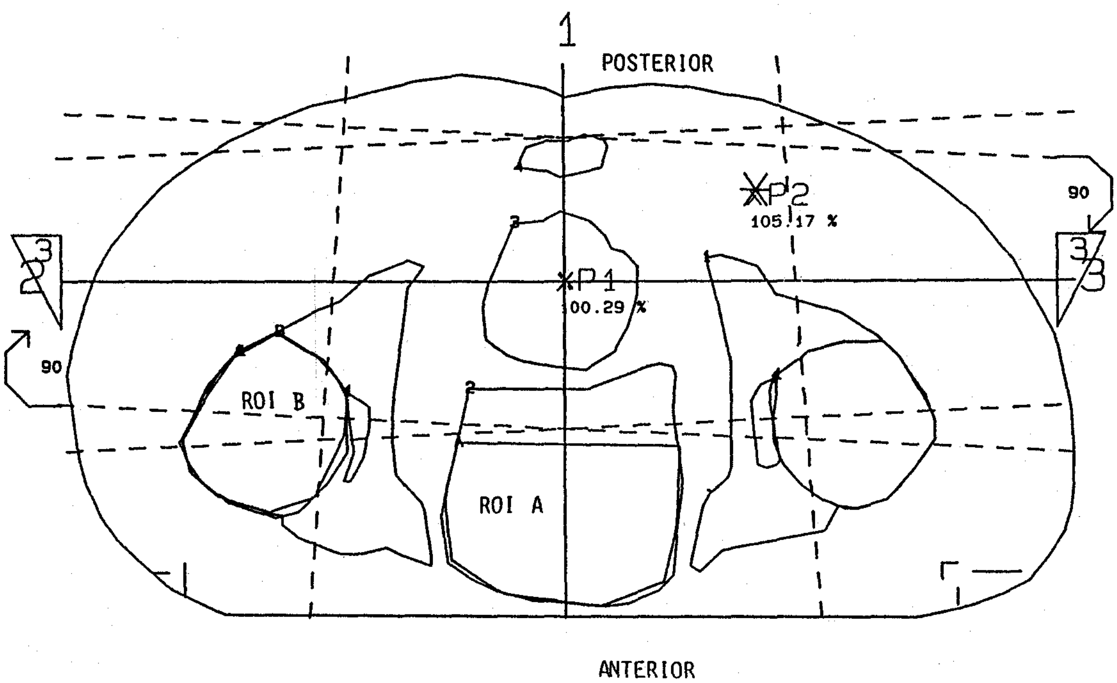

Fig. 1. Transverse contour,field configuration, Region of interest A (anterio half of bladder), Region of interest B (rt femoral head), and P1 (isocenter) and P2 (dmax point).

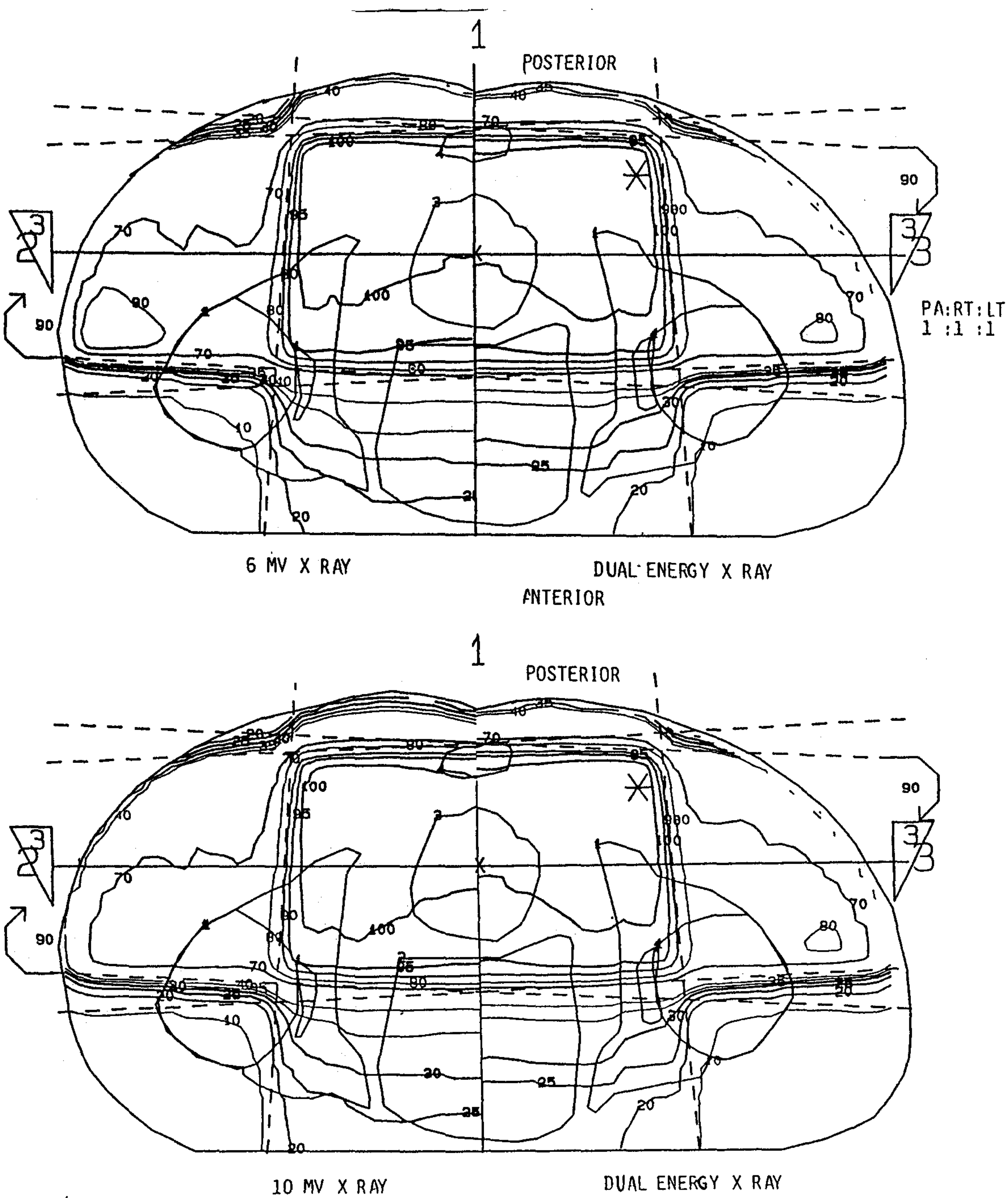

Fig. 2. Comparison of isodose curves obtained with 3 field technique using combined 6 MV and 10 MV dual energy photon vs 6 MV single photon (A) or 10 MV single photon (B).

beam over single energy when isodose are compared.

Table 1 shows maximal, minimal and average dose to the bladder contour with different treatment energy. Comparision is made dual energy photon beam with single energy X-ray. There is 8.2

Table 1. Comparison of % Dose in the Region of Interest and % Difference between Dual Energy and Single Energy X Ray Beam

Case	ROI	Dual X ray dose			6 MV dose			10 MV dose		
		Max	Min	Ave	Max (%)	Min (%)	Ave (%)	Max (%)	Min (%)	Ave (%)
1	A	52.1	31.7	39.1	55.8 (7.1)	34.0 (7.2)	42.0 (7.4)	54.9 (5.4)	35.3 (11.2)	42.4 (8.4)
	B	104.7	28.6	81.3	106.5 (1.8)	29.8 (4.4)	83.6 (2.8)	105.7 (0.9)	28.0 (−1.9)	82.6 (1.6)
2	A	55.7	34.3	42.1	59.6 (7.0)	36.9 (7.5)	45.5 (8.2)	58.4 (4.8)	37.9 (10.4)	45.3 (7.6)
	B	95.0	12.3	48.0	94.4 (−0.6)	13.2 (7.8)	48.5 (1.0)	96.4 (1.5)	11.9 (−2.7)	49.6 (3.2)
3	A	52.5	31.7	39.7	56.0 (6.7)	33.6 (5.9)	42.3 (6.4)	55.7 (6.0)	36.3 (14.2)	43.7 (10.0)
	B	92.4	5.7	42.6	93.3 (1.0)	6.2 (10.1)	44.2 (3.9)	94.1 (1.9)	5.4 (−5.0)	42.8 (0.5)
4	A	49.0	30.0	38.1	51.3 (4.7)	31.0 (3.4)	39.6 (3.8)	52.0 (6.0)	33.7 (12.3)	41.4 (8.6)
	B	98.9	11.8	55.2	99.7 (0.9)	12.8 (8.8)	56.6 (2.5)	100.1 (1.3)	11.3 (−3.7)	56.8 (2.7)
5	A	49.0	34.2	41.0	52.1 (6.3)	36.6 (7.0)	44.0 (7.3)	51.4 (4.9)	37.7 (10.2)	44.1 (7.5)
	B	99.2	7.5	40.9	101.5 (2.4)	8.0 (6.5)	43.6 (6.5)	100.9 (1.8)	7.2 (−4.6)	42.9 (4.9)
6	A	47.5	33.8	40.7	51.9 (9.3)	36.2 (7.0)	44.1 (8.5)	51.0 (7.3)	37.7 (11.5)	44.4 (9.2)
	B	94.1	13.9	60.8	94.3 (0.2)	15.4 (10.9)	61.1 (0.5)	95.5 (1.6)	13.5 (−2.7)	61.4 (1.0)
7	A	52.4	30.8	39.1	56.4 (7.7)	33.2 (8.0)	42.4 (8.3)	55.1 (5.3)	34.7 (13.0)	42.6 (8.8)
	B	102.5	11.5	73.1	102.6 (0.1)	13.3 (15.2)	73.4 (0.4)	102.8 (0.3)	11.0 (−4.3)	73.9 (1.2)
8	A	48.0	31.7	39.0	53.3 (10.9)	34.4 (8.5)	42.7 (9.4)	51.0 (6.1)	35.3 (11.5)	42.3 (8.5)
	B	82.4	10.6	49.3	81.5 (−1.1)	12.0 (13.1)	47.8 (−3.2)	83.3 (1.1)	9.9 (−6.7)	48.0 (−2.7)
9	A	47.6	31.2	38.3	51.3 (7.9)	33.4 (7.1)	41.1 (7.4)	50.9 (7.0)	35.4 (13.4)	42.0 (9.8)
	B	98.7	14.8	65.0	97.9 (−0.8)	15.7 (- 5.7)	65.2 (0.3)	99.3 (0.7)	15.3 (2.8)	66.4 (2.2)
10	A	40.9	23.7	31.9	44.7 (9.2)	26.2 (10.5)	35.1 (10.0)	43.8 (7.1)	27.2 (14.8)	35.2 (10.4)
	B	90.3	8.8	43.6	94.0 (4.1)	8.7 (−1.6)	47.3 (8.7)	91.8 (1.6)	8.7 (−1.1)	43.4 (−0.4)
11	A	52.8	32.7	40.6	57.5 (8.9)	35.1 (7.4)	43.8 (8.0)	55.6 (5.3)	36.4 (11.5)	43.9 (8.3)
	B	92.9	5.1	38.7	93.1 (0.3)	5.4 (4.5)	39.1 (1.0)	94.1 (1.3)	4.7 (−8.9)	38.7 (−0.1)
12	A	39.0	23.3	31.7	44.3 (13.8)	25.6 (10.2)	35.7 (12.8)	41.2 (5.7)	25.9 (11.2)	34.1 (7.6)
	B	101.5	9.9	78.0	103.4 (1.9)	12.4 (25.9)	79.1 (1.5)	102.0 (0.6)	9.5 (−3.9)	77.8 (−0.2)
13	A	52.7	39.3	43.4	58.1 (10.2)	42.6 (8.4)	47.3 (9.1)	55.4 (5.2)	42.9 (9.2)	46.7 (7.6)
	B	105.8	38.9	77.0	106.7 (0.8)	40.6 (4.5)	77.1 (0.0)	105.5 (−0.3)	36.7 (−5.5)	76.6 (−0.6)

Table 1. Continued

Case	ROI	Dual X ray dose			6 MV dose			10 MV dose		
		Max	Min	Ave	Max (%)	Min (%)	Ave (%)	Max (%)	Min (%)	Ave (%)
14	A	59.7	39.6	44.8	64.0 (7.2)	42.6 (7.4)	48.4 (8.1)	62.1 (4.0)	43.1 (8.8)	47.8 (6.8)
	B	99.1	19.6	66.7	99.4 (0.3)	20.9 (6.5)	67.5 (1.2)	99.9 (0.7)	19.0 (−2.9)	66.8 (0.2)
15	A	41.7	20.8	28.5	44.3 (6.2)	22.0 (5.9)	30.3 (6.2)	43.8 (5.0)	23.6 (13.6)	31.1 (8.9)
	B	86.2	4.7	38.1	87.6 (1.6)	4.9 (5.8)	39.7 (4.3)	86.4 (0.2)	4.4 (−6.2)	37.4 (−1.7)
Average	A				(8.2)	(7.4)	(8.1)	(5.7)	(11.8)	(8.5)
	B				(1.1)	(8.7)	(2.5)	(1.0)	(2.8)	(1.2)

%(4.7%~13.8%) and 5.7%(4.0%~7.7%) increase in maximal dose to the bladder with 6 MV and 10 MV X-ray, respectively. There is 8.1%(3.8~12.8%) and 8.5%(6.8%~8.5%) increase in average dose to the bladder with 6 MV and 10 MV X-ray, respectively. There is 7.4%(3.4%~10.5%) and 11.8%(8.8%~14.8 %) increase in minimal dose of bladder adjacient to intestine with 6 MV and 10 MV X-ray, respectively.

ROI B represents femoral head dose. Increase in maximal dose to the femoral head is about 1% in 6 MV and 10 MV X-ray. Minimal dose to femoral head shows 8.5% increase with 6 MV X-ray 3.8% decrease with 10 MV X-ray. Average dose to the femoral head is increased in 2.1% with 6 MV X-ray and decreased in 0.8% with 10 MV X-ray.

Dmax is increased in 1.3% with 6 MV and decreased 0.8% with 10 MV X-ray.

DISCUSSION

With clinically resectable cancer, sufficient data have been accumulated to demonstrate that the association of moderate to high dose pre or postop irradiation can significatnly reduce the incidence and morbidity of local recurrence in high risk patients when compared with operation alone[1~4].

Perineal irradiation if performed adequately using anterior and posterior parallel opposed fields frequently results in considerable early morbidity[8]. This occurs because adequate coverage involves inclusion of skin.

When supervoltage equipment is used if the edge of anterior and posterior pararell opposed radiation field extend beyond the perineum, radiation dose to perineal surface will be enhanced, while the skin sparing is achived at the enterance and exit surface of the portals. Toxicity is enhanced because the beams, which are passing through the air have no intervening tissue to attenuate them. Perineal reaction may be diminished by not only not irradiating the perineum but also by angling the beam or by three or four field[6,8].

Distinctive advantage of dual energy photon beam therapy over single photon is that average dose to the bladder is decreased in around 8% as compared with 6 MV and 10 MV X-ray without much difference in dmax dose. Dose of small intestine which is located adjactent to the anterior wall of bladder representing minimal dose to the bladder is decreased in 7.4% and 11.8% in comprarision with 6 MV and 10 MV X-ray, respectively. When one use high energy the exit dose will be increased which contribute increase in small intestinal or genital organ dose and also perineal dose will not be adequate with vertex field due to skin sparing effect.

Moderate energy beam lowers exit dose to the small intestine and genital organ but lateral field dose will be increased. Combination of medium and high energy beam can overcome above disadvantage. One can adequately cover the perineum with 6 MV with reasonable skin sparing and lower exit dose to small intestine and scrotum or labia, and minimize soft tissue dose in lateral field using 10 MV X-ray.

Above data suggests that if rectal cancer is not well controlled with 4500~5000 rads one can increase dose using 3 field technique higher than dose previously applied with pararell opposing field with delivering acceptable dose to the critical organ. Hoskin et al[1] and Gunderson[9] recommand higher dose to the tumor bed in patient with perirectal soft tissue invasion or lymph node positive patient. Tepper et al[10] reported 53% of local failure with stage C3 disease with dose of 5040 rad or greater. This paper shows that one can increase total dose of 7~12% to the tumor volume with same dose to critical organ when dual photon energy X-ray is used.

SUMMARY

Dual energy photon beam with 6 MV and 10 MV X-ray combination therapy for 15 patient with diagnosis of rectosigmoid or rectal cancer was evaluated to see any advantage over single energy photon beams.

The results are as follows.

1. Compare to 6 MV single photon beams, dual energy photon beams give 8.1% less dose to the bladder, 7.4% less dose to the anterior bladder wall adjacient to small intestine, and 1.3% less dose to Dmax and 2% less dose to the lateral femoral head.
2. Compare to 10 MV single energy X-ray, dual energy X-ray beams give 8.5% less dose to the bladder, 11.8% less dose to the anterior wall of bladder, minimal change of the dose in dmax and lateral femoral head, and less skin sparing effect to the perineum.

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국문초록 =

6 MV 및 10 MV X-ray의 이중에너지를 생성하는 방사선 발생장치의 임상적 이용

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최근에 선형가속기에 대한 제작기술의 발달로 하나의 기계에서 두가지 X-선이 생성된다. 이러한 기계적 특성을 충분히 이용할 수 있도록 임상적으로 어떠한 장점이 있는지 아는 것은 매우 중요하다. 특히 SAD 방법으로 치료시 다른 에너지를 사용하여야 될 경우 환자를 다른에너지가 있는 치료실로 이동시키지 않아도 되는 장점이 있다. 저자는 직장암 환자 15예를 중심으로 6 MV와 10 MV X-선의 에너지를 복합적으로 사용하여 치료를 하였을때 단일에너지인 6 MV 혹은 10 MV X-선을 이용했을 때와 등량곡선의 분포도 및 선량률의 차이를 비교하였다. 선량 계산은 치료계획용 Mevaplan 콤퓨터를 이용하였다. 정상조직에 들어가는 방사선량의 차이를 계산하기위해 방광 및 우측 대퇴부를 임의의 점으로 잡아 콤퓨터에 입력시켜 그 부위의 최대선량 최소선량 및 평균선량을 구하였다.

6 MV 및 10 MV의 이중에너지 X-선을 이용하였을 때 6 MV 단일 에너지 X-선으로 치료시 보다 방광의 평균 방사선량은 8.1% 감소하였고 방광 전벽 방사선량 즉 소장과 근접해 있는 부위는 7.4%의 감소를 보였다. 최대선량치 Dmax는 1.25%감소하였다. 대퇴부위의 평균 방사선량은 2% 감소하였다.

이중에너지 X-선 치료는 10 MV 단일에너지와 비교하여 방광의 평균 방사선량은 8.5% 감소하였고, 소장근접 부위는 11.8% 감소하였다. 최대선량치 Dmax는 0.8%의 증가로 거의 차이가 없었다. 대퇴부위 방사선량은 0.8%증가로 비슷하였다. 그외 회음부 및 전골전방 부위는 전방조사야에 10 MV 대신 6 MV를 씀으로써 피부 sparing 효과를 줄여주어 충분한 방사선량을 줄 수 있었다.

위의 결과로 이중에너지 X-선 치료는 정상조직의 손상은 같게주며 종양부위의 방사선량을 7~12%정도 올려줄 수 있는 장점이 있음을 알 수 있었다.