

New Techniques in Hadrontherapy: Intensity Modulated Proton Beams

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Abstract

Inverse planning and intensity modulated (IM) X-ray beam treatment techniques can achieve significant improvements in dose distributions comparable to those obtained with forward planned proton beams. However, intensity modulation can also be applied to proton beams and further optimization in dose distribution can reasonably be expected.

A comparative planning exercise between IM X-rays and IM proton beams was carried out on two different tumor cases: a pediatric rhabdomyosarcoma and a prostate cancer.

Both IM X-rays and IM protons achieved equally homogenous coverage of the target volume in the two tumor sites. Predicted NTCPs were equally low for both treatment techniques. Nevertheless, a reduced low-to-medium dose to the organs at risk and a lesser integral non-target mean dose for IM protons in the two cases favored the use of IM proton beams.

KEYWORDS: Protons, X-rays, intensity modulation.

1. Introduction

In recent years, the potential advantages of proton beams over conventional X-ray beams in cancer radiotherapy have been shown for numerous tumor sites. In general, proton therapy is a strong candidate whenever the planning target volume (PTV) is extremely close to the organs at risk (OAR).

Nowadays, inverse planning and intensity modulated (IM) X-ray beams can also achieve significant improvements in dose distributions such that the gap between proton beam techniques and X-ray techniques has closed considerably.

However, it has been showed that intensity modulation can be also applied to proton beams [1]. In contrast with IM photons, the three dimensional localization of dose provided by the proton Bragg peak allows for a three dimensional intensity modulation. Further improvements in dose distribution can reasonably be expected with IM proton beams when compared with IM X-ray beam treatment techniques. Hence, there is a pressing need to conduct photon-proton planning comparisons with the best candidates on each side.

The present study is a planning comparison between IM X-rays and IM proton beams for two example cancer cases: a pediatric rhabdomyosarcoma and a prostate cancer.

2. Materials and methods

Planning CT scans were performed for each case in treatment position. The target volume and the normal critical structures were defined in each CT data set.

• Case 1: Paraorbital pediatric rhabdomyosarcoma. The clinical target volume (CTV) was defined by

the gross tumor image as seen in the diagnostic CT/MRIs. The planning target volume (PTV) was drawn 5 mm around the CTV. Critical structures such as the lenses, optic nerves, retinas, lachrymal and salivary glands were outlined. The prescribed dose to the PTV was 50.4 Gy. A 9 co-planar beam plan for both IM X-rays (energy of 6 MV) and IM proton beams (energy of 170 MeV) was generated.

• Case 2: Prostate cancer. The CTV included the prostate gland and the seminal vesicles. The PTV was drawn 10 mm around the CTV, except at the boundary between the anterior rectal wall and the prostate where a 6 mm margin was used. Critical structures such as the bladder, the rectum, and the femoral heads were outlined. The prescribed dose to the PTV was 81 Gy. A 5 co-planar beam plan for both IM X-ray (energy of 15 MV) and IM proton beams (energy of 200 MeV and 177 MeV) was generated.

The IM plans were generated using an inverse planning program developed at the PSI [1] (the IM X-ray plan was generated using a similar method of optimization as that described by Bortfeld et al. [2]). The tolerance doses and the relative priorities assigned for the critical structures in both optimization procedures are shown in Table I.

The plans were scored via dose-volume histograms (DVHs) and computation of normal tissue complication probabilities (NTCPs) for the OARs with the Lyman model [3] and also measurement of integral dose.

3. Results

Comparative DVHs for the PTV and for some representative organs at risk (OARs) for Case 1 and

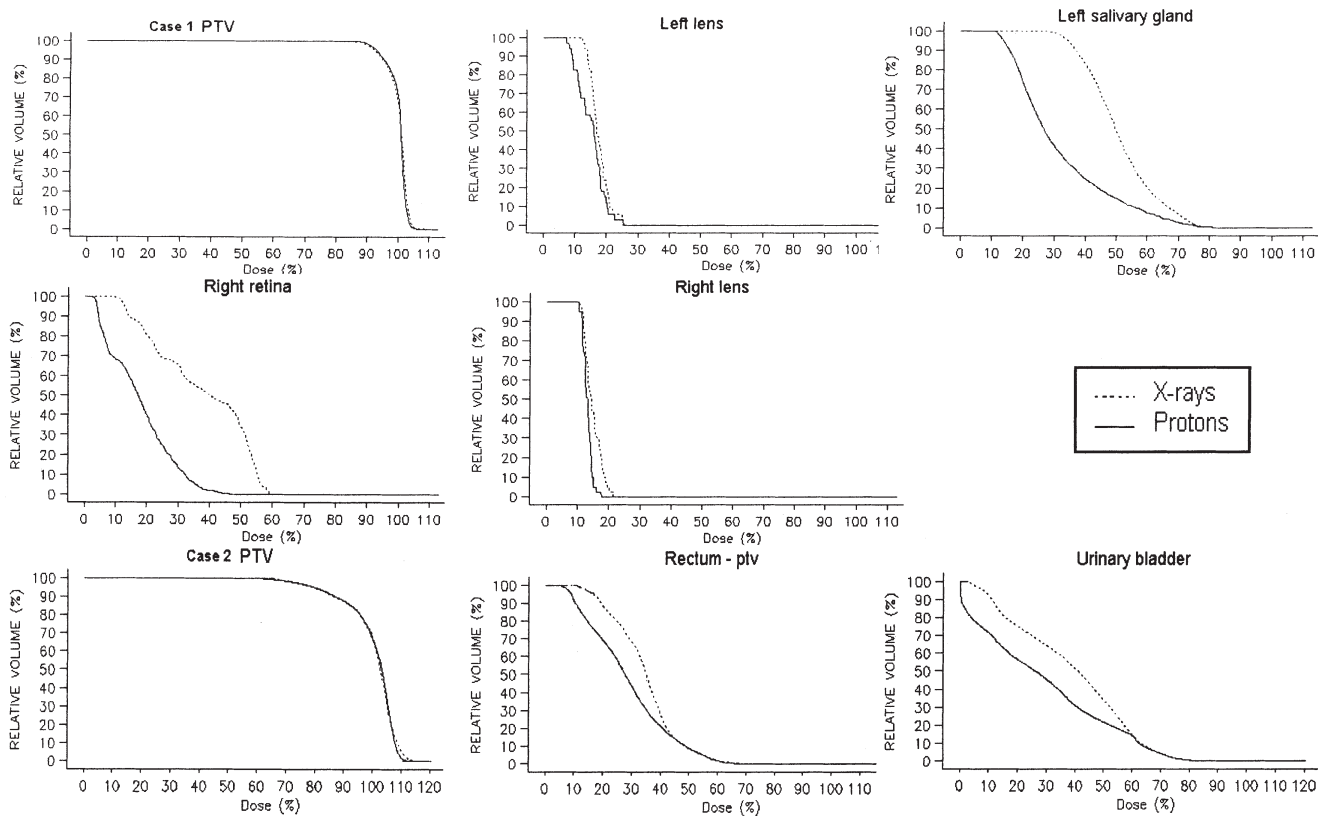


Fig. 1 – Comparative DVHs for case 1 (rhabdomyosarcoma) and case 2 (prostate cancer).

Case 2 are shown in Figure 1. In both cases the two IM techniques succeeded in similarly covering the PTV with almost no differences in dose homogeneity, while all critical structures were less irradiated with the IM proton plans. For case 2 the IM plans demonstrate a reduced dose homogeneity in the PTV as a consequence of the compromise in the target dose established by the overlapping rectum and bladder dose constraints (Table I).

NTCPs for Case 1 are presented in Table II. The NTCPs were predicted for cataracts, for severe re-

tinal toxicity and for the homolateral parotid gland. Both IM plans give a low risk (< 2%) of developing cataracts, retinal morbidity, and mouth dryness.

For Case 2, the estimated NTCP for the bladder as well as for the femurs were negligible with both techniques (<0.1%). The NTCP for the rectum (grade 3 late effects) was 1.1% for IM X-rays and 0.7% for IM protons, that is an optimal low risk with both techniques.

The mean integral non-target dose was measured for each plan. In both cases, this was 2 times higher with IM X-rays compared to IM protons.

Table I – Percentage tolerance doses (TD) and the relative priorities for each OARs for case 1 and 2.

CASE 1-OAR	TD	Relative priority
Rectum	40	2
Bladder	58	1
Overlap rectum-PTV	70	5
Overlap bladder-PTV	80	5
CASE 2-OAR	TD	Relative priority
Retina	89	10 (right)/5 (left)
Lens	20	10 (right)/5 (left)
Parotid glands	69	5
Lachrymal glands	60	10
Overlap retina-PTV	96	10

4. Discussion

In this study, for both the cancer cases selected as examples, DVHs always predict a more favorable dose distribution for IM proton beams, mainly due to a lower low-to-medium range of dose delivered to the OARs. Nevertheless, the high-dose range delivered to the critical structures and the dose homogeneity in the PTV were similar with both IM

Table II – Predicted NTCPs for case 1.

OAR	IM X-rays	IM protons
Retina	0.1 (right)	0.1 (right)
Lens	1.7 (right)/1.6 (left)	1 (right)/1.1 (left)
Parotid	0.1 (right)	0 (right)

techniques. Therefore a significant gain in NTCPs could not be expected with IM protons when compared to IM X-rays.

On the other side, the mean integral non target dose was higher for IM X-rays by a factor 2 (inferior low-to-medium dose range with IM protons as mentioned above). The dose-related risk of radiation-induced second malignancies has been well established, especially in children. This risk might be significantly reduced with both IM techniques, particularly with IM protons.

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